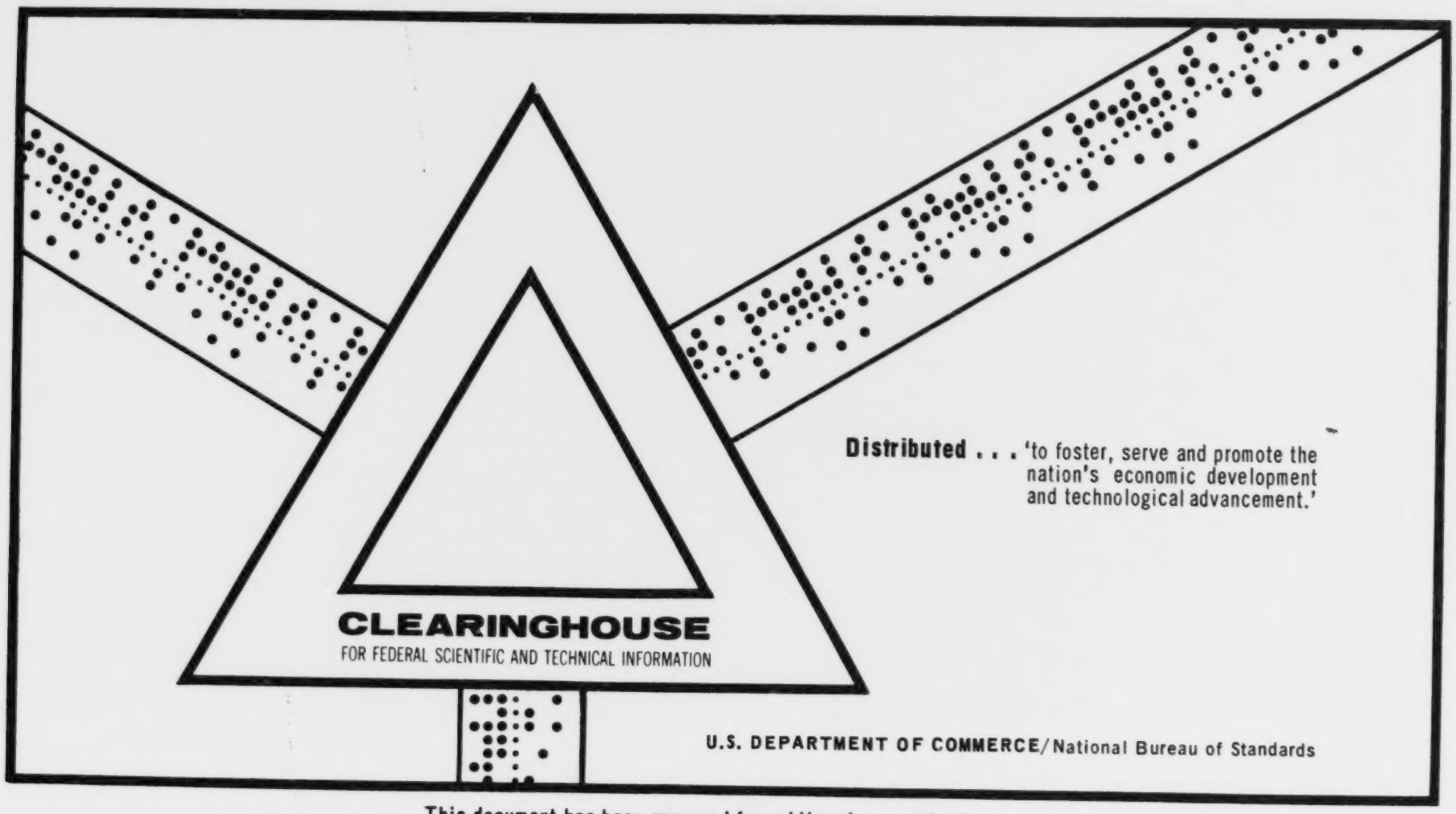
PB 187 760

COST OF WASTEWATER TREATMENT PROCESSES

David DiGregorio

Dorr-Oliver, Incorporated
Stamford, Connecticut

December 1968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ROBERT A. TAFT WATER RESEARCH CENTER

REPORT NO. TWRC-6

PB187760

COST OF WASTEWATER TREATMENT PROCESSES

ADVANCED WASTE TREATMENT RESEARCH LABORATORY - VI

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FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
OHIO BASIN REGION
Cincinnati, Ohio

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COST OF WASTEWATER TREATMENT PROCESSES

by

DORR-OLIVER, INCORPORATED

David DiGregorio, Project Engineer

The Advanced Waste Treatment Research Laboratory

Robert A. Taft Water Research Center

This report is submitted in fulfillment of Contract No. 14-12-60 between the Federal Water Pollution Control Administration and Dorr-Oliver, Incorporated.

U. S. Department of the Interior
Federal Water Pollution Control Administration
Cincinnati, Ohio

December, 1968

FOREWORD

In its assigned function as the Nation's principal natural resource agency, the United States Department of the Interior bears a special obligation to ensure that our expendable resources are conserved, that renewable resources are managed to produce optimum yields, and that all resources contribute their full measure to the progress, prosperity, and security of America -- now and in the future.

This series of reports has been established to present the results of intramural and contract research studies carried out under the guidance of the technical staff of the FWPCA Robert A. Taft Water Research Center for the purpose of developing new or improved wastewater treatment methods. Included is work conducted under cooperative and contractual agreements with Federal, state, and local agencies, research institutions, and industrial organizations. The reports are published essentially as submitted by the investigators. The ideas and conclusions presented are, therefore, those of the investigators and not necessarily those of the FWPCA.

Reports in this series will be distributed as supplies permit. Requests should be sent to the Office of Information, Ohio Basin Region, Federal Water Pollution Control Administration, 4676 Columbia Parkway, Cincinnati, Ohio 45226.

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ABSTRACT

New capital cost information for conventional and some advanced wastewater treating processes has been collected and correlated in terms of capacity or physical size. Operating costs have been calculated for some of the processes. Conventional processes considered include comminution, grit removal, primary settling, biological treatment by activated sludge and trickling filter, final settling, and sludge treatment and disposal. Advanced processes include phosphate extraction, chemical clarification and sand filtration, carbon adsorption, and membrane ultrafiltration.

Most of the cost information was obtained from sales information of Dorr-Oliver, Incorporated. Supplementary data from other sources were utilized, however, when necessary.

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INTRODUCTION

An important goal in the wastewater treatment field today is the economic optimization of treatment systems. To optimize a treatment system requires reasonably accurate estimates of the capital and operating costs of the system components. Although some of the necessary cost information is available in the literature, much of it remains in the hands of equipment manufacturers. In this report an attempt has been made to present cost correlations that include in most cases unpublished data from Dorr-Oliver, Incorporated. Other data sources have been used when necessary for completeness.

It must be pointed out that the costs presented here may differ slightly from independent estimates published by FWPCA. The differences probably result from the fact that assumptions must be made about certain factors comprising capital and operating costs. These assumptions vary among cost estimators. The assumptions made here are based upon the experience of Dorr-Oliver and are considered realistic.

METHOD OF APPROACH

An extensive survey of Dorr-Oliver sales information yielded a large volume of data relating equipment costs to loading and equipment size. Costs, including profit and installation, were updated by applying factors derived from known equipment price increases. Construction costs, including material, labor, profit, engineer's and contractor's fees, were estimated from company experience and updated with Engineering News Record Construction Cost Indexes. The information provided is concerned only with the unit process under consideration. No effort was made to evaluate the costs of land, excavation or inter-process requirements.

The method of least squares was used to correlate the generated data. In many cases the data could be described by a straight line, $Y = aX + b$, on an arithmetic or logarithmic plot. Where this description was not satisfactory, an equation of the form $Y = \frac{1}{aX + b}$ was used. A computer program was written to facilitate the least square computations.

SEWAGE PRETREATMENT

Comminution

Comminutors are sized on a volume flow basis, therefore, the plot of cost versus average daily flow is a good cost performance representation for most domestic sewage applications. Insofar as comminutors must be capable of handling peak flows with a minimum head loss, design flow with respect to comminutors may be estimated at 2.5 times the average daily flow for reasonable size plants. Figure 1 shows a graphical representation of the cases studied for the comminution process. The cost as shown is for equipment only. No consideration was given to special housing or concrete structures. The statistical equation computed was:

$$\text{Log (Cost)} = 0.14 \text{ Log (MGD)} + 1.76$$

Cost = Hundreds of dollars

Grit Removal

The capital costs for hydrocyclone degritting are shown on Figure 2. This cost includes equipment and installation only since there are essentially no concrete requirements. The operating costs for this type of degritter are very low. Hydrocyclones, utilized for degritting purposes, will make separations in the range of 150 mesh or 104 microns on sand (hydrocyclones are available for separations as fine as 5 microns). This is based on a 2.7 specific gravity and solids in the feed less than 25% by weight. The equation computed was as follows:

$$\text{Log (Cost)} = 1.58 - 0.65 \text{ Log (MGD)}$$

Cost = Hundreds of dollars/MGD

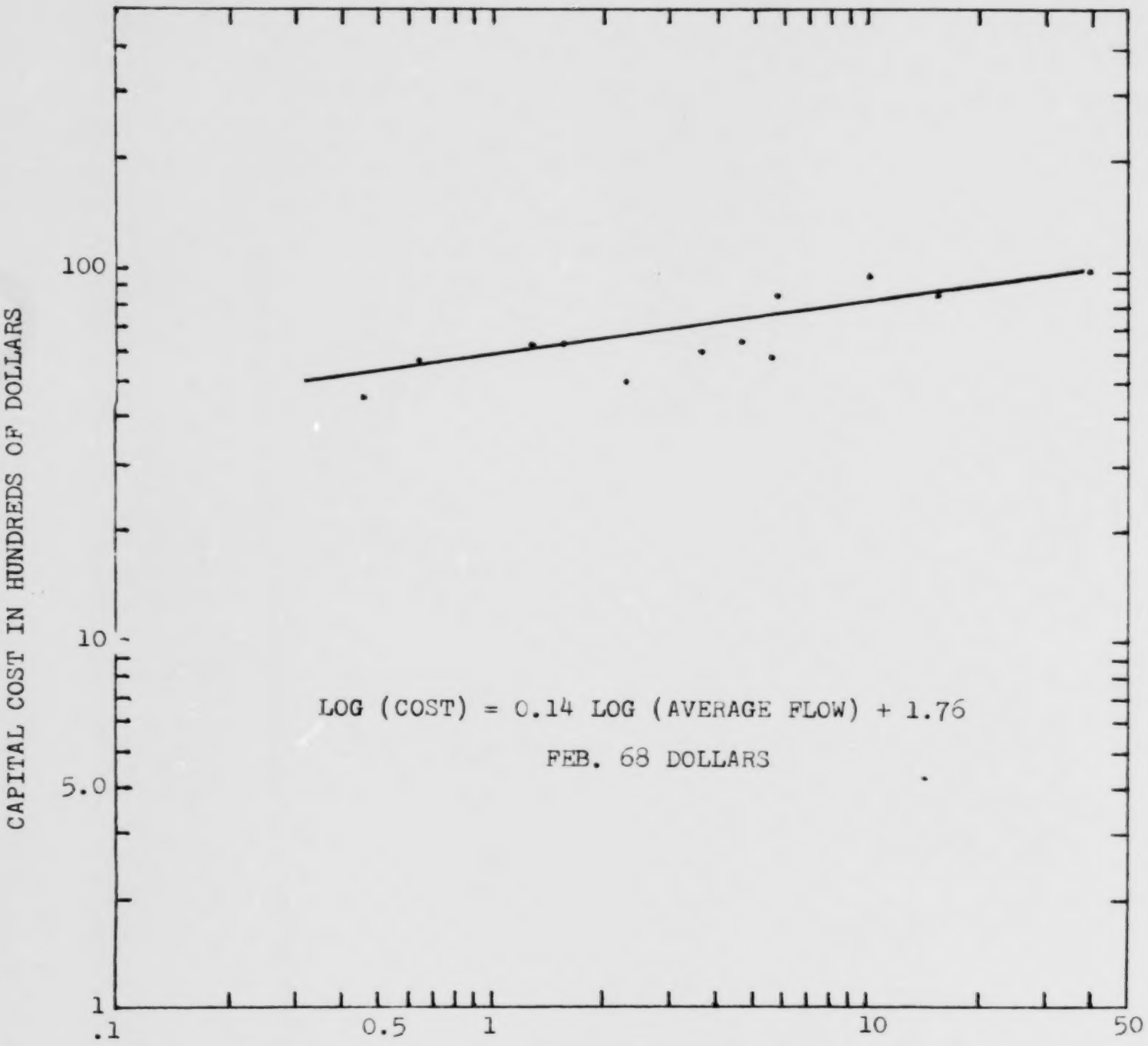
Detritus Removal

Figure 3 shows the capital costs for detritors. The cost includes all concrete plus detritus collecting and separating equipment. The unit will usually collect all grit coarser than 65 mesh. No more than 3% by weight of putrescible organic matter will normally be contained in the grit. The equation computed was:

$$\text{Log (Cost)} = \frac{1}{0.211 \text{ Log (Area)} + 0.073}$$

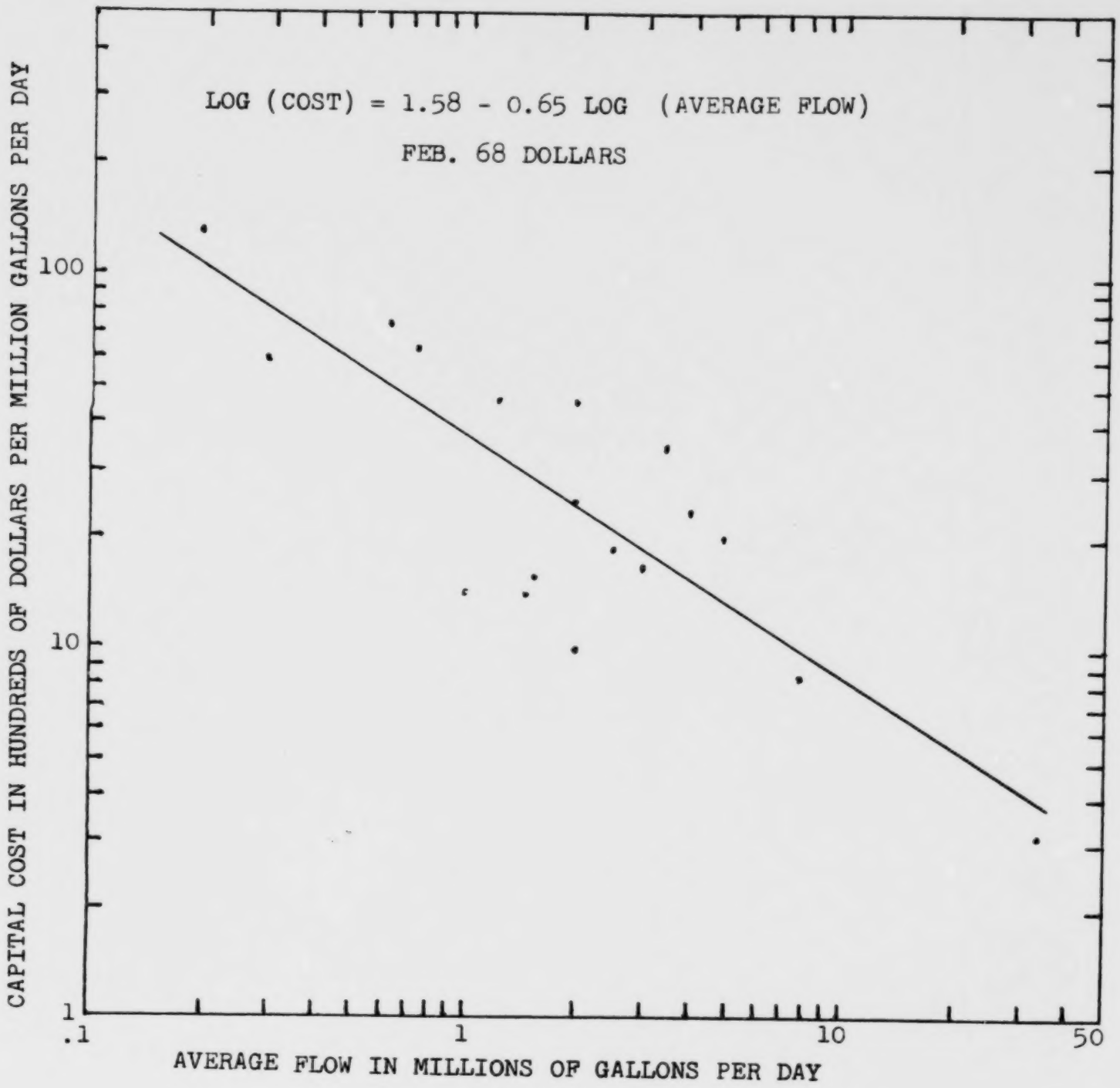
Cost = Dollars/square foot

Area = Square feet



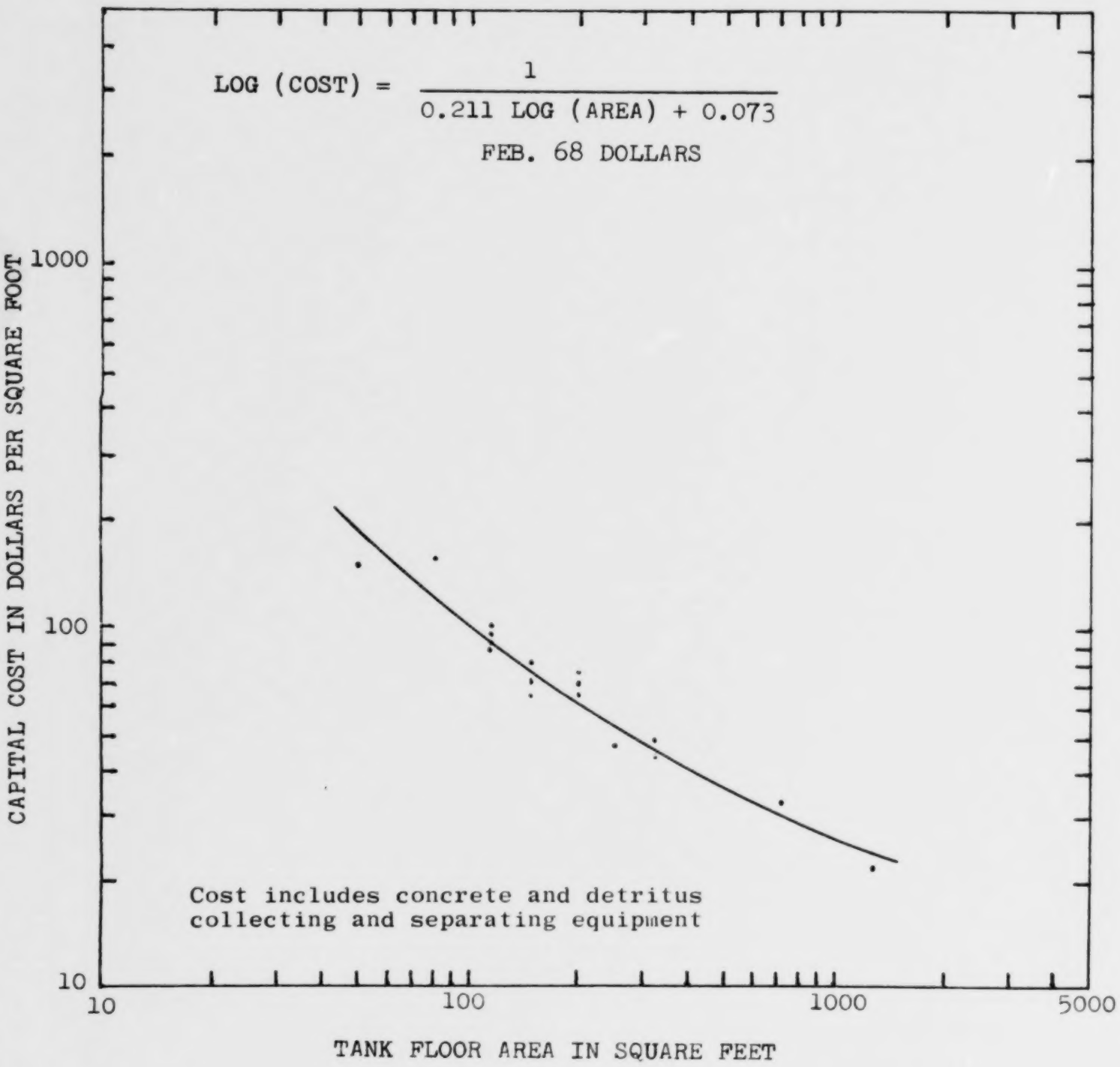
Capital Cost of Comminution Equipment
Versus Average Daily Flow

Figure 1



Capital Cost of Hydrocyclone Degritting
Equipment Versus Design Flow

Figure 2



Capital Costs of Detritors Versus Tank Floor Area

Figure 3

PRIMARY TREATMENT

Primary Sedimentation

The capital cost of primary sedimentation is shown on Figure 4. Tank floor surface area was plotted against total cost in dollars per square foot.

Performance of primary sedimentation is highly variable and subject to local conditions and sewage composition. Figure 5 represents actual operating data of primary clarifiers. While the curve does not permit absolute evaluation of clarification performance, it does present a good performance approximation and follows design criteria recommended by Dorr-Oliver. For example, primary clarifiers will normally provide 50-60% removal of total suspended solids when the overflow rate (OR) equals 100 gal./ft^2/day per foot of side water depth (SWD).

The equation computed for the capital cost of primary sedimentation was:

$$\text{Log (Cost)} = \frac{1}{0.233 \text{ Log (Area)} + 0.758}$$

Cost = Dollars/square foot

Area = Thousands of square feet

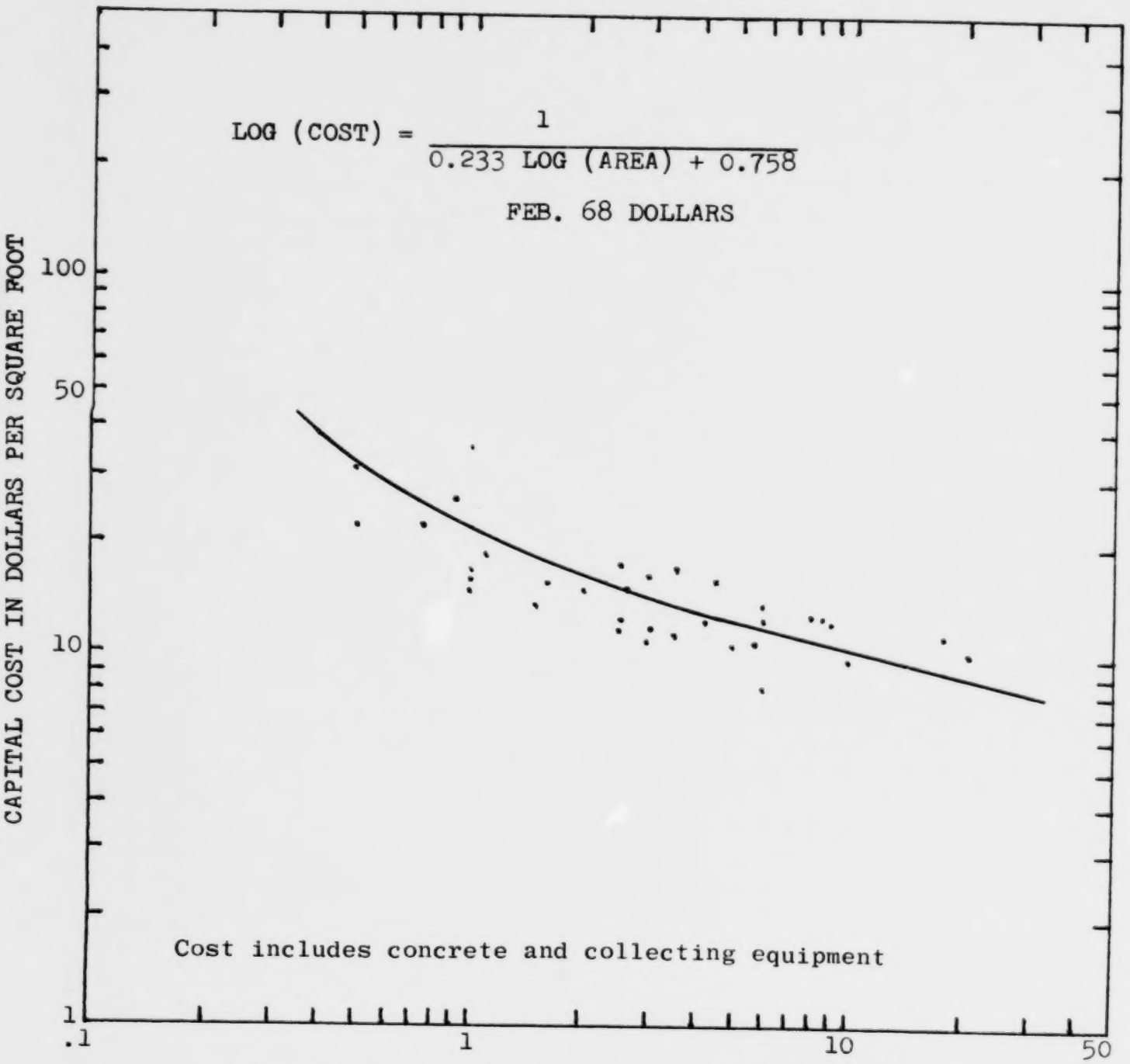
Digestion

Figure 6 shows the capital costs of sludge digestion. Total cost for this process includes all heating, mixing and gas requirements, sludge pumps, concrete tank requirements and a digester cover. The computed equation was:

$$\text{Log (Cost)} = \frac{1}{0.31 \text{ Log (Volume)} + 0.37}$$

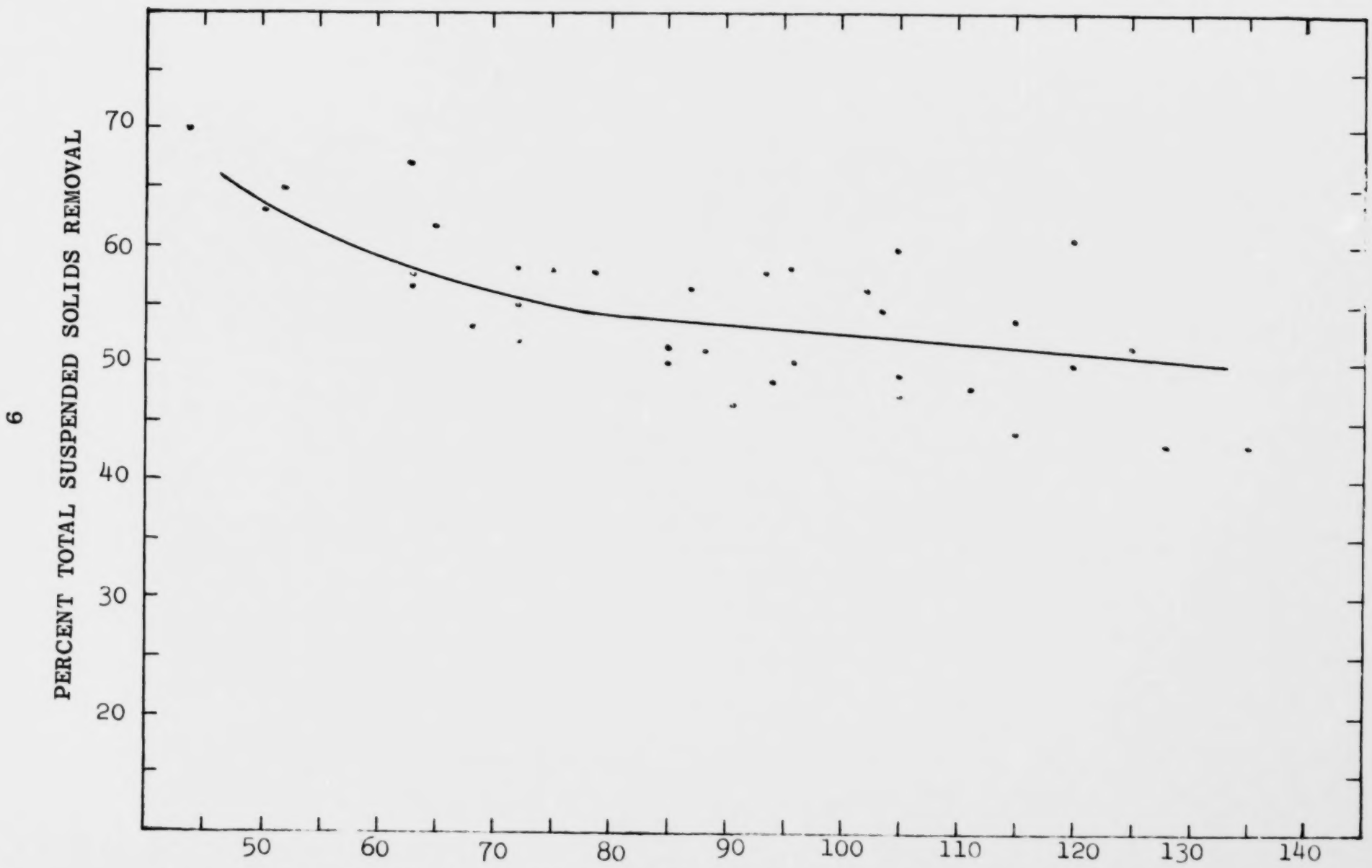
Cost = Tenths of dollars/cubic foot

Volume = Thousands of cubic feet



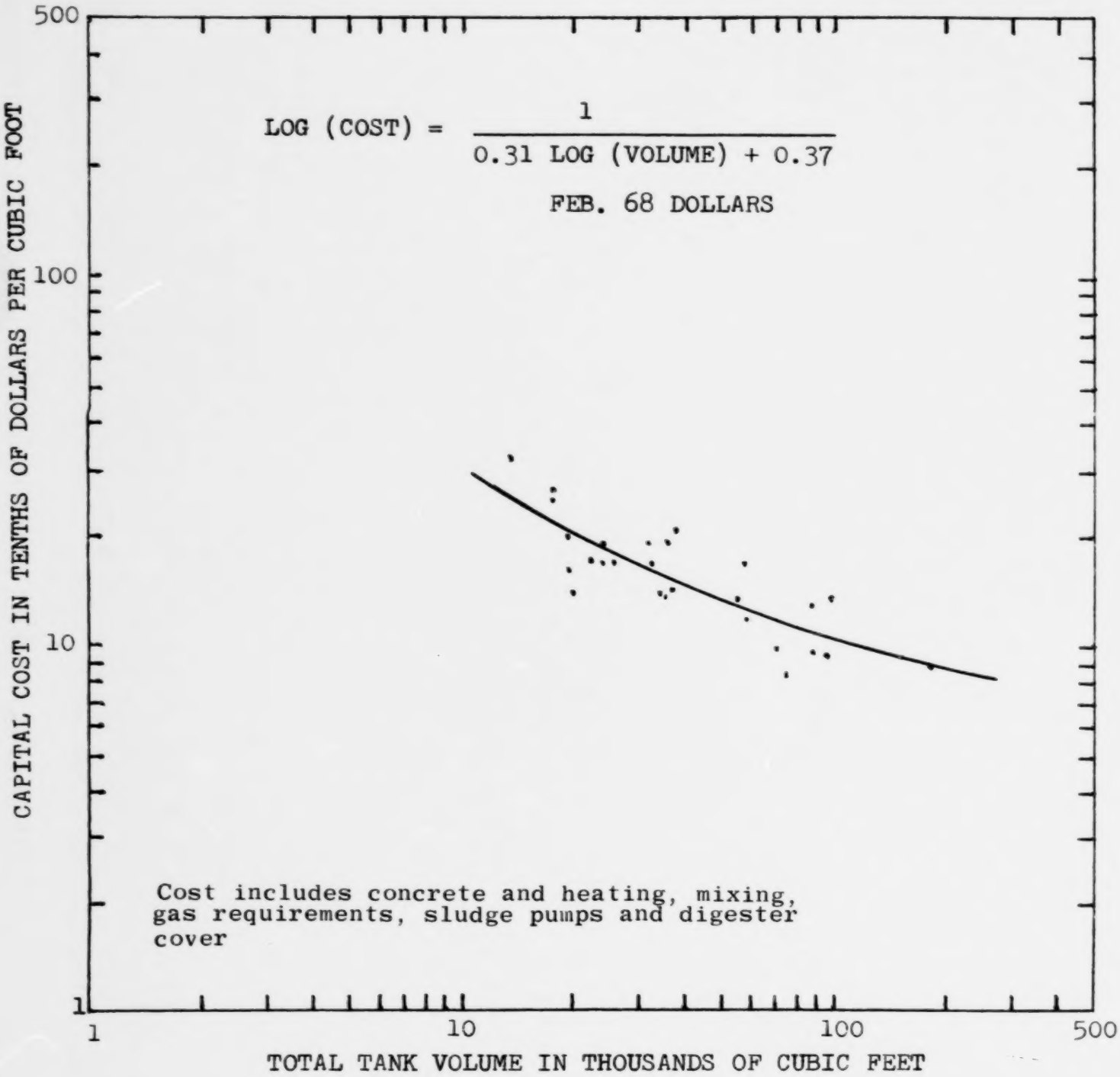
Capital Cost of Primary Sedimentation
Versus Tank Floor Area

Figure 4



Performance of Primary Clarifiers

Figure 5



Capital Cost of Sludge Digestion Versus Tank Volume

Figure 6

Activated Sludge

The activated sludge cost analysis is summarized on Figures 7-10. These curves were generated in a different manner from most work. A design was performed for plant sizes ranging from 0.5 to 20 MGD using Dorr-Oliver design criteria and available equipment information. It was assumed that the aeration step would follow primary sedimentation, the BOD removal in the primary step would be 30% and that the activated sludge system would remove 90% of the remaining BOD. Tank depth was about 15 feet.

The capital cost of activated sludge shown on Figure 7 includes concrete requirements and mechanical aerator costs. Figures 8-9 represent blower capital (including prime movers) and power costs respectively. Aerator power costs (aerating and mixing) are shown on Figure 10. Power was assumed at 1.5 cents/kwh. The computed equations are given below.

Activated sludge capital cost:

$$\text{Log (Cost)} = 0.806 \text{ Log (Volume)} + 0.306$$

Cost = Thousands of dollars

Volume = Thousands of cubic feet

Blower capital cost:

$$\text{Cost} = 3.58 \text{ Capacity} + 2.53$$

Cost = Thousands of dollars

Capacity = Thousands of SCFM

Blower operating cost:

$$\text{Cost} = 0.68 \text{ Capacity} + 0.14$$

Cost = Dollars/hr

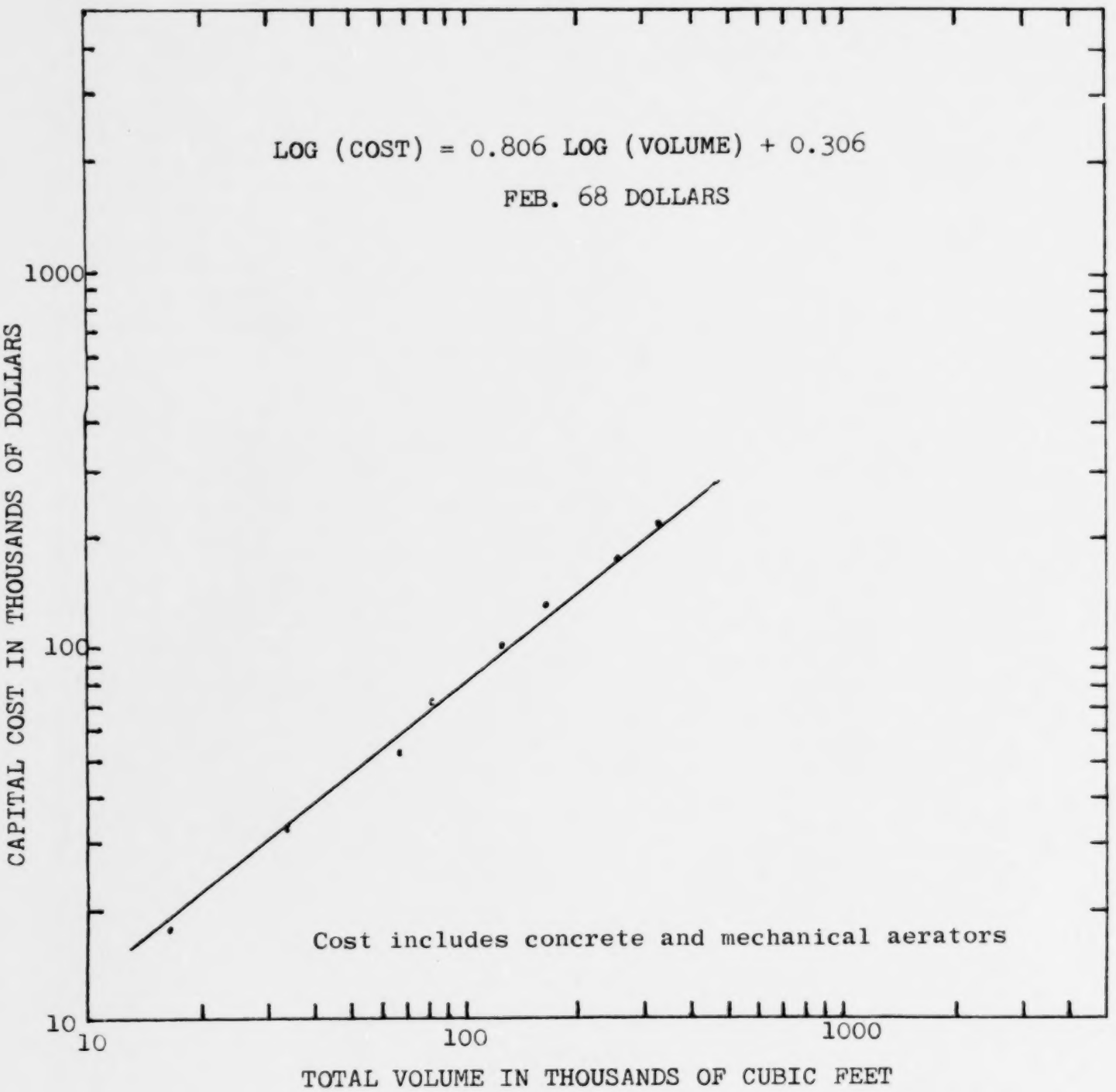
Capacity = Thousands of SCFM

Aerator operating cost:

$$\text{Cost} = 1.42 \left(\frac{\text{Volume}}{100{,}000}\right)$$

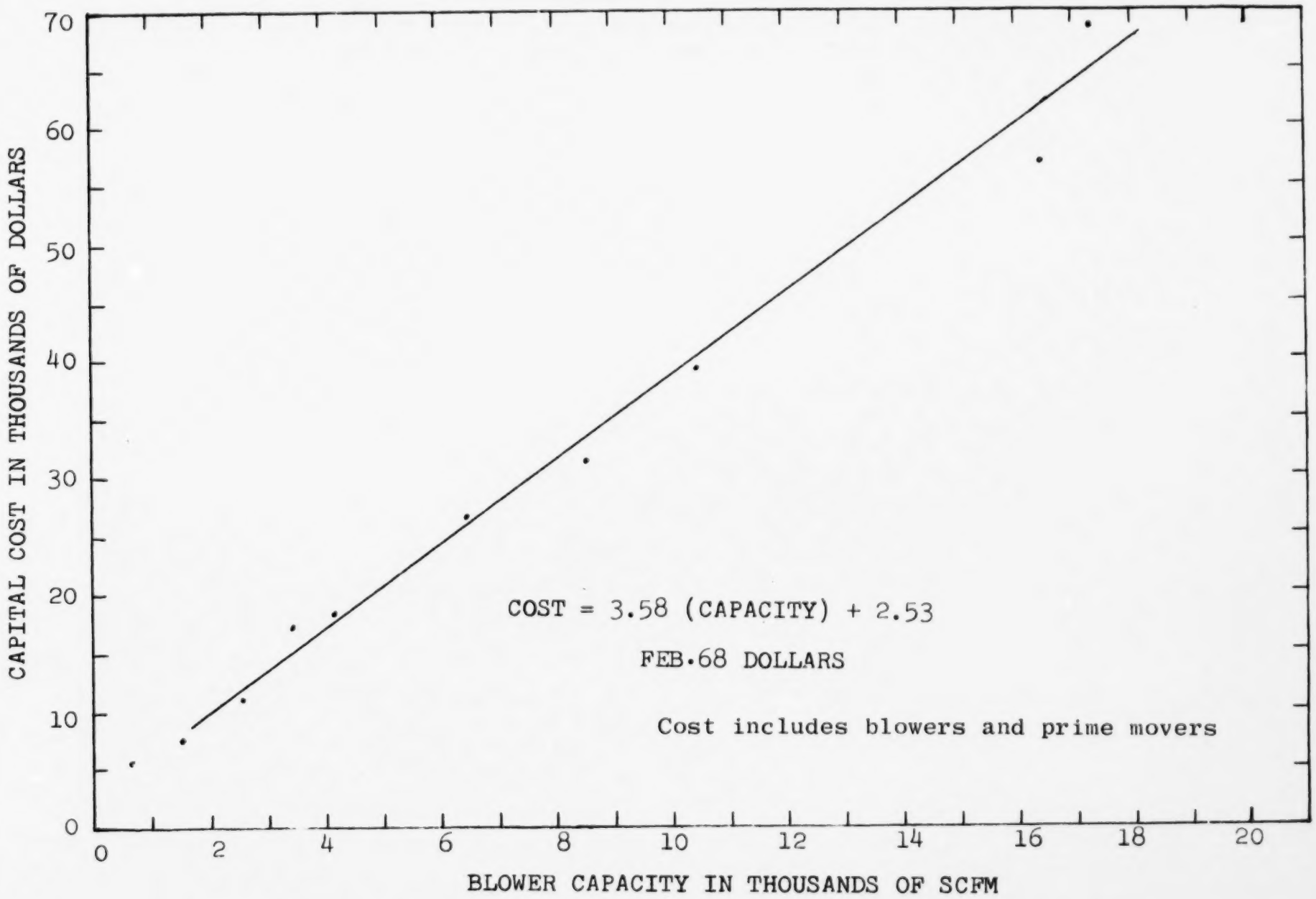
Cost = Dollars/hr

Volume = Cubic feet



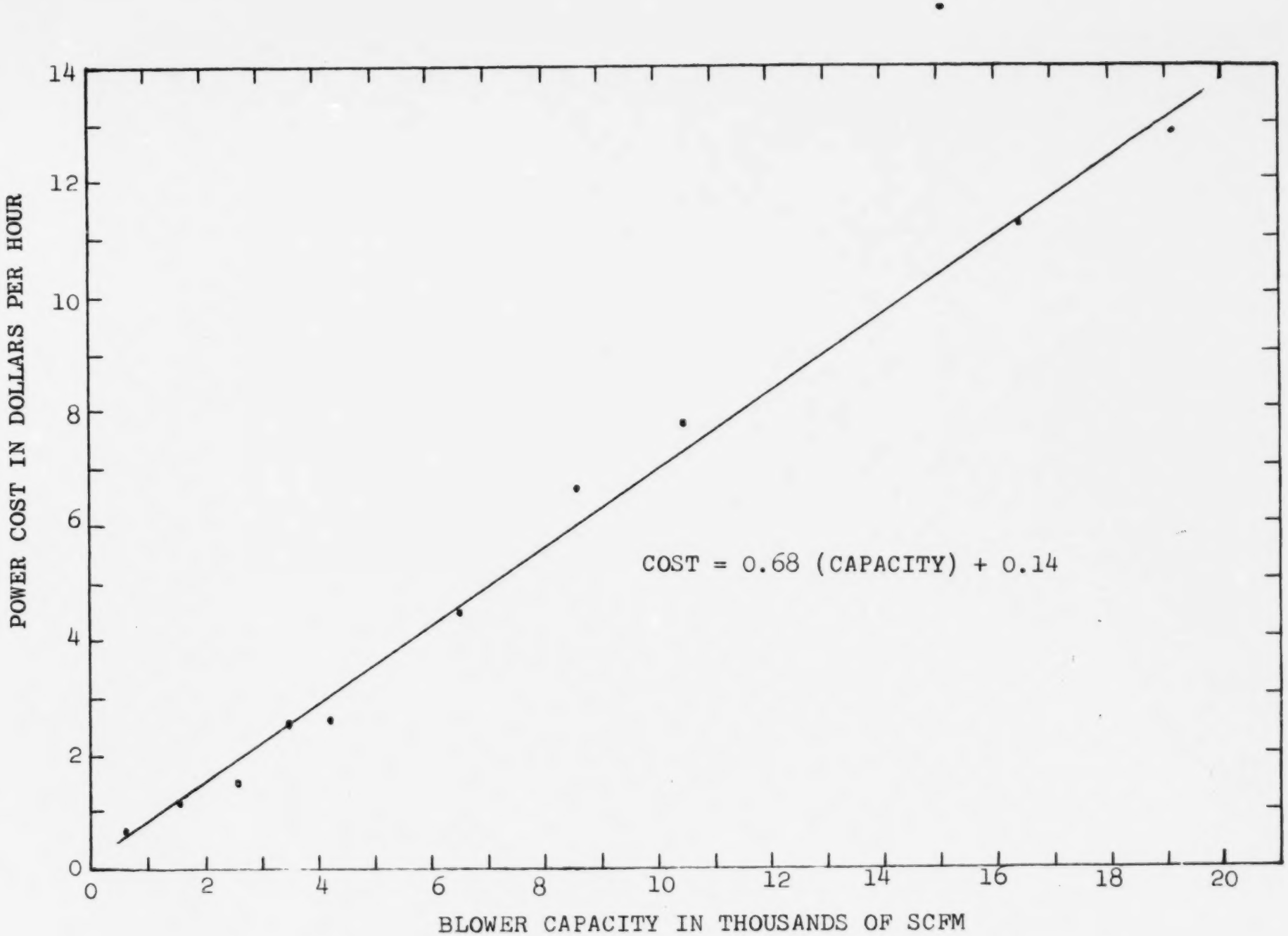
Capital Cost of Activated Sludge
Versus Tank Volume

Figure 7



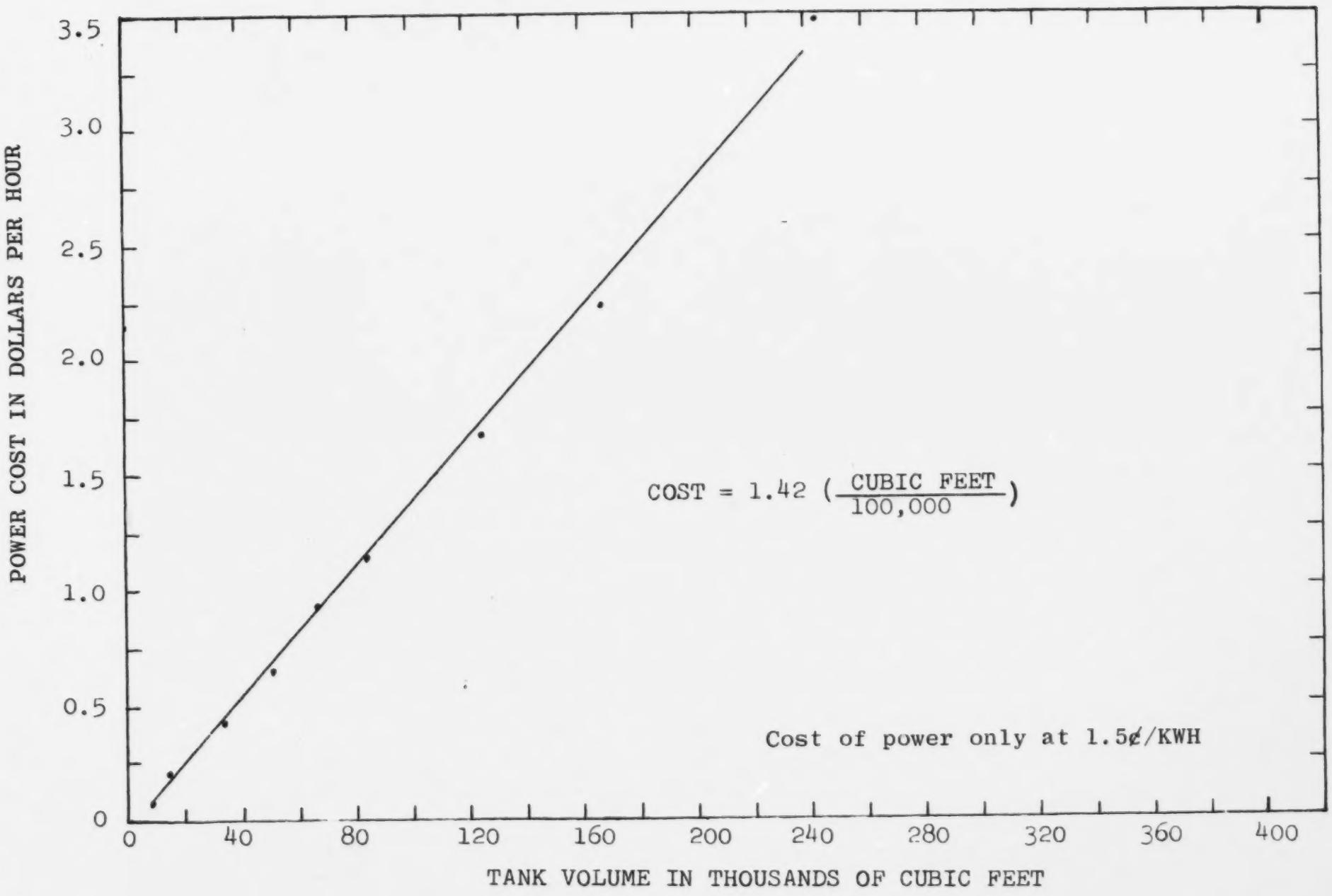
Capital Cost of Blowers Versus Blower Capacity

Figure 8



Operating Cost of Blowers Versus Blower Capacity

Figure 9



Operating Cost of Aerators Versus Tank Volume

Figure 10

Trickling Filtration

Figure 11 represents the capital cost of trickling filtration. Included in this cost are concrete and equipment requirements underdrainage and media. The media bed was assumed to be rock at a cost of 3 dollars/ton (4.5 dollars/cubic yard). The cost of rock media is extremely variable. Its cost, more than anything else, is a function of how far it has to be shipped to the plant location. Underdrainage blocks were assumed to cost 1 dollar/square foot. This will also vary considerably with freight charges. Media plus underdrainage, at the assumed prices, constitute about 30% of the total trickling filter cost for a reasonable size unit. It is therefore recommended that some consideration be given to possible price variations of these items.

The degree of purification realized by trickling filtration is affected by weather conditions, sewage composition and operating policy. The effects of high rate operation or recirculation on performance are great. Fair and Geyer[1] state that these effects can be evaluated using the following equation:

$$VF = \frac{y_0}{13800} \left(\frac{P_2}{100-P_2}\right)^2$$

V = Acre-feet of filter

F = Recirculation factor

y_0 = Daily BOD loading

P_2 = Degree of purification

The equation computed for capital costs of trickling filters was:

$$\text{Log (Cost)} = \frac{1}{0.18 \text{ Log (Area)} + 0.78}$$

Cost = Dollars/square foot

Area = Thousands of square feet

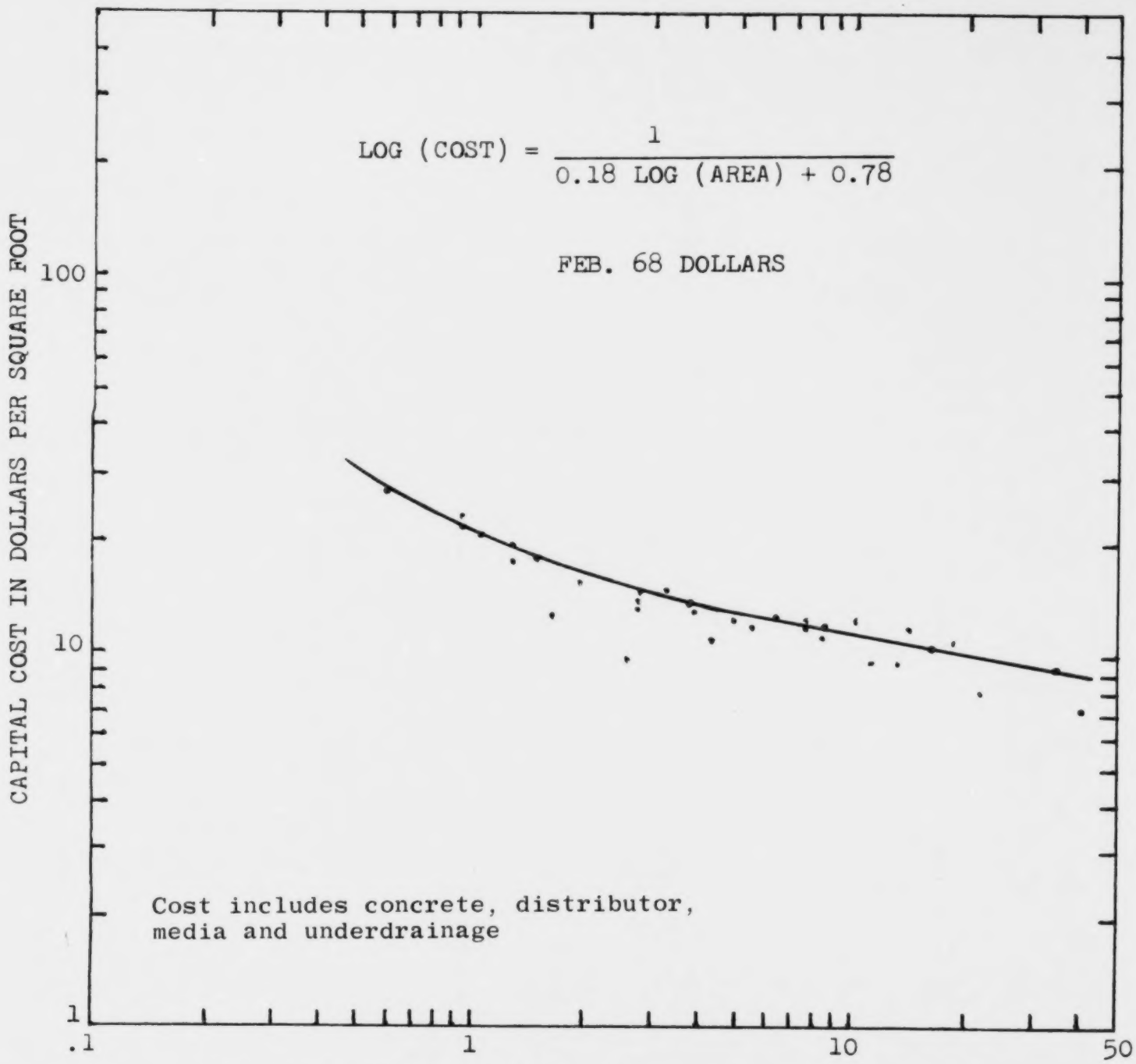
Final Clarification

The capital costs of final clarification are shown on Figure 12 and include equipment and concrete construction costs. The computed equation was:

$$\text{Log (Cost)} = \frac{1}{0.20 \text{ Log (Area)} + 0.57}$$

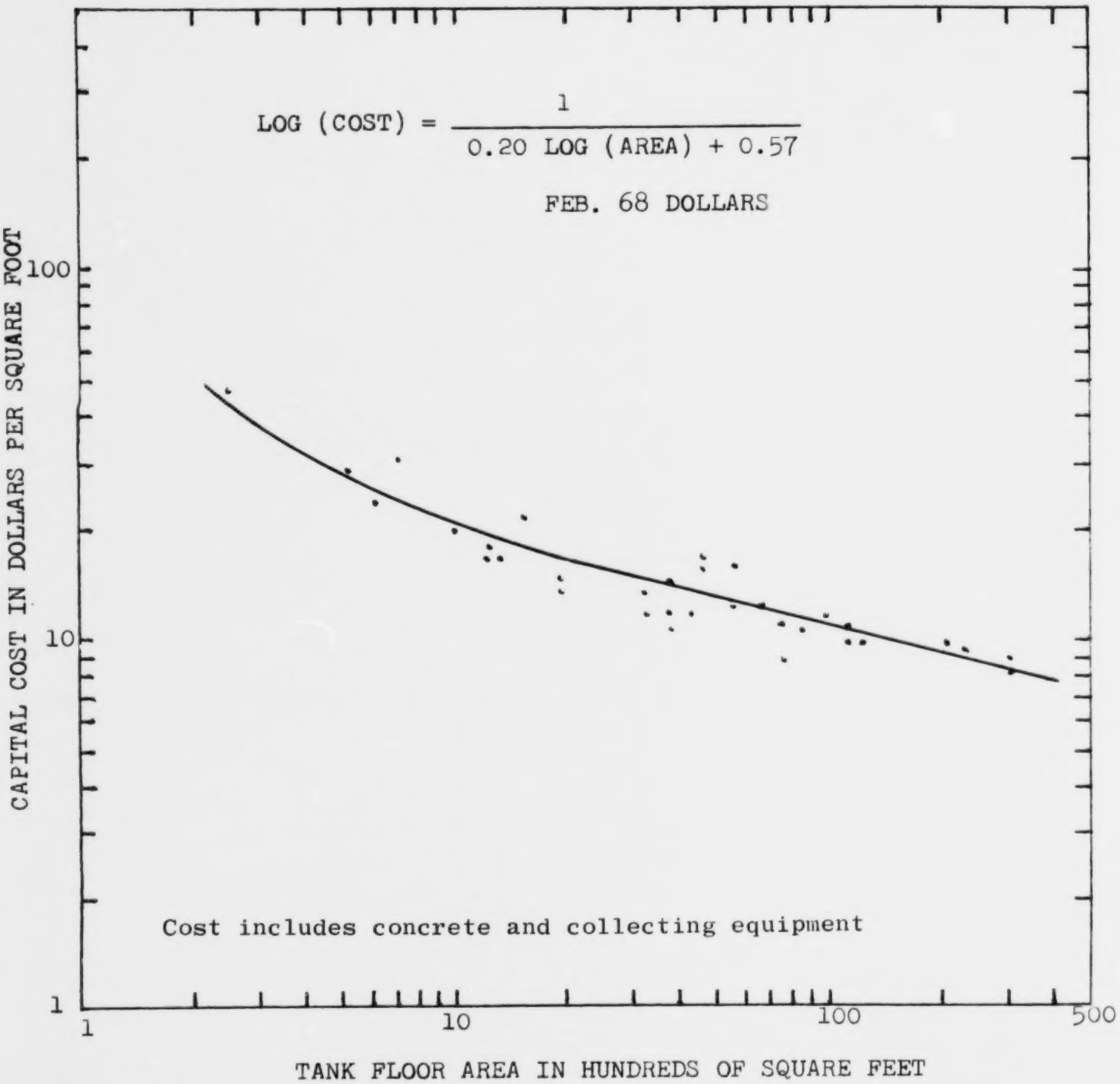
Cost = Dollars/square foot

Area = Hundreds of square feet



Capital Cost of Trickling Filtration
Versus Tank Floor Area

Figure 11



Capital Cost of Final Clarification
Versus Tank Floor Area

Figure 12

Elutriation

Sludge elutriation is a washing operation whereby substances that interfere physically with chemical conditioning and filtration are washed out of the sludge. There is a reduction in required chemical conditioning of sewage sludge when filtration is preceded by elutriation.

Since the introduction of polymers in place of dewatering aids such as ferric chloride, sludge elutriation has been regarded highly impractical and unnecessary. Chemical conditioners must initially satisfy the coagulant demand of the liquid fraction of sludge which is exerted by the alkalinity of bicarbonates. Polymers have the advantage of not reacting with the alkalinity thus reducing chemical (polymer) requirements without the elutriation process. With polymer flocculents continually improving sludge elutriation will prove to be unnecessary and both physically and economically unattractive.

An economic comparison of dewatering using ferric chloride and lime yielded the following costs:

Primary, digested sludge	9 Dollars/Ton Dry Solids
Primary, digested, elutriated (including amortized capital cost)	4.5 Dollars/Ton Dry Solids
Primary, digested (using polymers)	4.5 Dollars/Ton Dry Solids

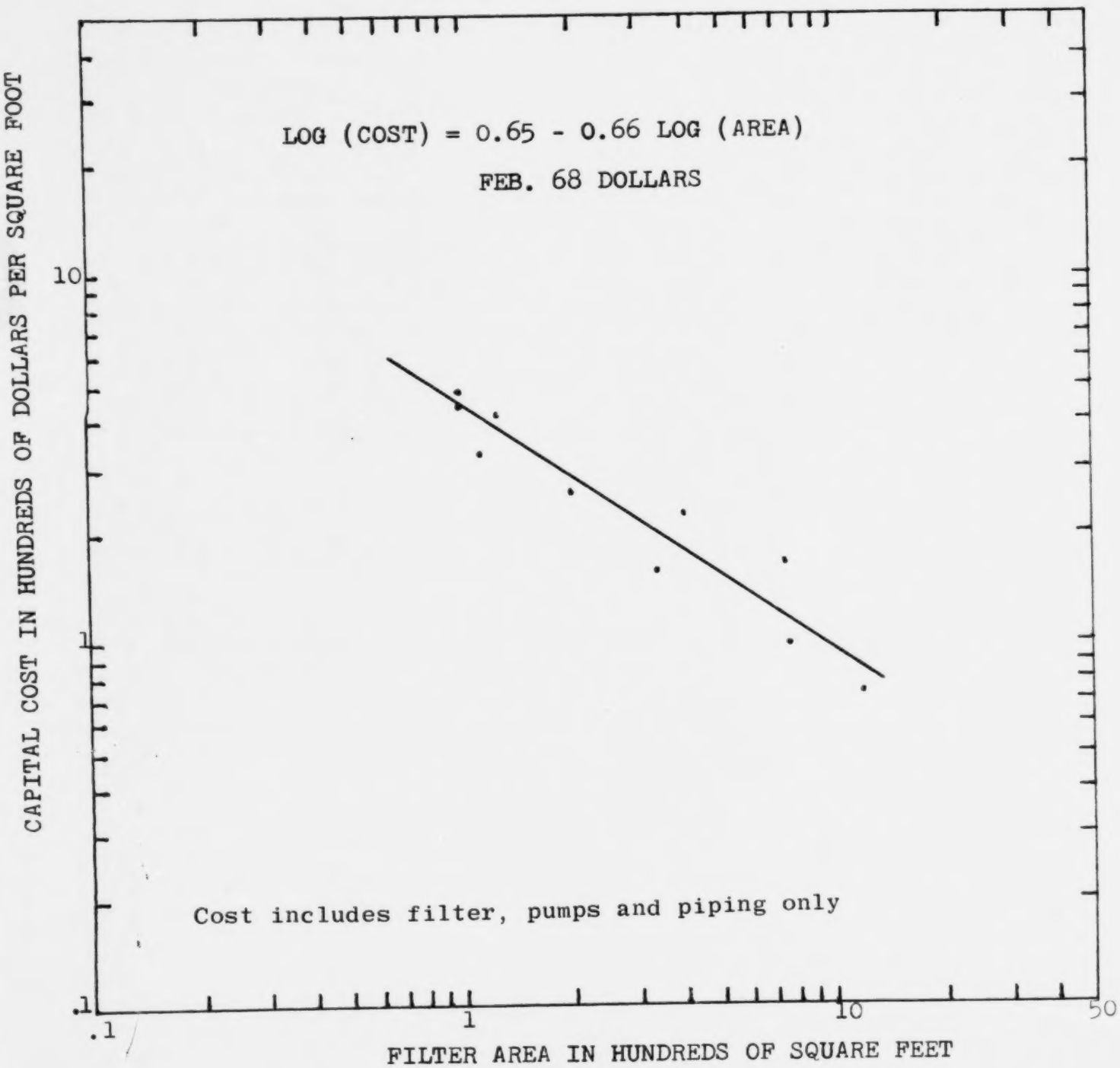
The elutriation step was assumed to be the two stage countercurrent type and chemical requirements were computed from Genter's Equations[2]. The sludge was assumed to have the following characteristics: pH = 7, solids = 5%, volatile content = 45%, alkalinity of digested sludge = 3000 ppm and alkalinity of elutriated sludge = 300 ppm (90% removal). Ferric chloride was taken at 4 cents/lb. and lime at 1 cent/lb.

What these results indicate is that there is a choice between elutriating before dewatering or dewatering using polymers. Considering the nature of the elutriation process, the space required, the additional operating equipment and so on, the responsible engineering approach will be to use polymer sludge conditioning.

Vacuum Filtration

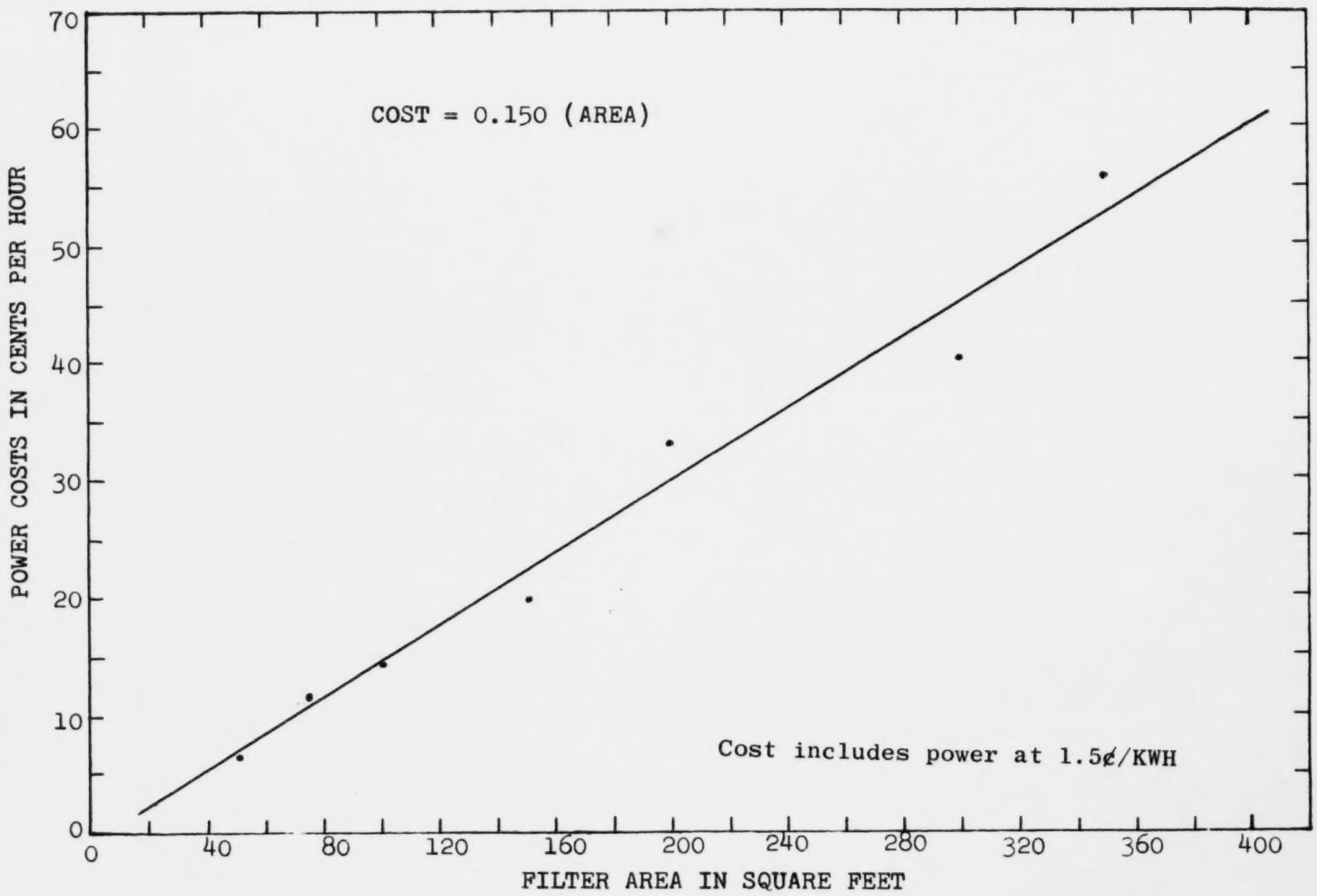
Figure 13 shows the capital costs of vacuum filtration. Included are all necessary piping and pumps associated with the operation of the vacuum filter.

Operating costs were divided into power and chemical costs. Power costs in cents per hour of operation are plotted on Figure 14. Chemical



Capital Cost of Vacuum Filtration
Versus Filter Area

Figure 13



Vacuum Filter Power Costs Versus Filter Area

Figure 14

requirements for vacuum filtration are highly variable and subject to chemical and physical characteristics of the sludge. Ferric chloride requirements (percent of dry solids in feed) may be found from Genter's Nomograph[2] on Figure 15 or by calculation:

$$\text{Total } FeCl_3\ (\%) = \text{Liquid Demand } \% + \text{Solids Demand } \%$$

$$\text{where Liquid Demand } (\%) = \frac{H_2O\ (\%) \times \text{ppm Alkalinity}^* \times 0.0001 \times 1.8}{\text{Solids in Sludge } (\%)}$$

$$\text{and Solids Demand } (\%) = \frac{1.6 \times \%\ \text{Volatile Matter (Dry Basis)}}{\%\ \text{Ash (Dry Basis)}}$$

Lime (hydrated) dosage may be approximately determined by knowing the percent solids, methyl orange alkalinity and pH:

(1) $$\text{Percent lime required for } CO_2 = \frac{CO_2\ (\text{ppm}) \times 100 \times 1.68}{\%\ \text{Solids} \times 1{,}000{,}000}$$

$$\text{where } CO_2\ (\text{as } CO_2) = \frac{\text{Alkalinity (ppm as } CaCO_3)}{\text{Ratio}}$$

(Ratio from Figure 16)

(2) Percent lime required for ammonium carbonate =

$$\frac{\text{Ammonium Carbonate (ppm)} \times 100 \times 0.74}{\%\ \text{Solids in Sludge} \times 1{,}000{,}000}$$

where Ammonium Carbonate Alkalinity = Methyl Alkalinity - CO_2 Alkalinity

(3) $$\text{Percent lime required for } FeCl_3 = \frac{\text{Atomic Wt. Lime} \times 3 \times FeCl_3\ \text{Used}^{**}}{\text{Atomic Wt. } FeCl_3 \times 2}$$

(4) Percent lime required for solids demand = % solids in sludge. Total percent lime as $Ca(OH)_2$ required =(1)+(2)+(3)+(4). This method will only yield approximate chemical requirements. Actual filter performance, more than anything else, will determine quantities of chemicals used.

Performance of vacuum filters is subject to many variables. The physical and chemical characteristics of the sludge will greatly affect the production rate of filtration. Table 1 provides rough figures of production based on degree of treatment. These are very general rates and can vary with chemical dosage, type of chemical conditioner, nature of solid content and chemical content of sludge among others.

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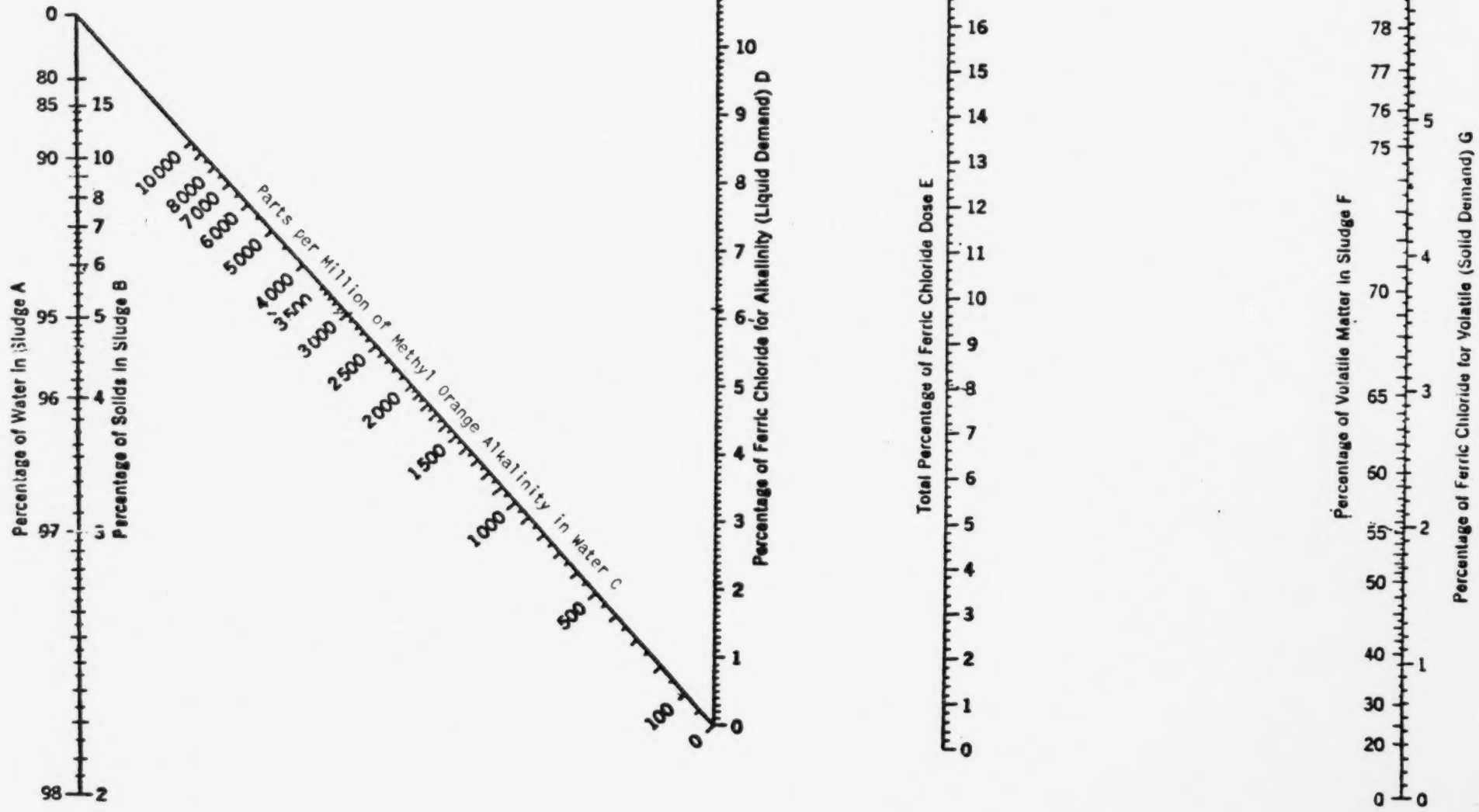
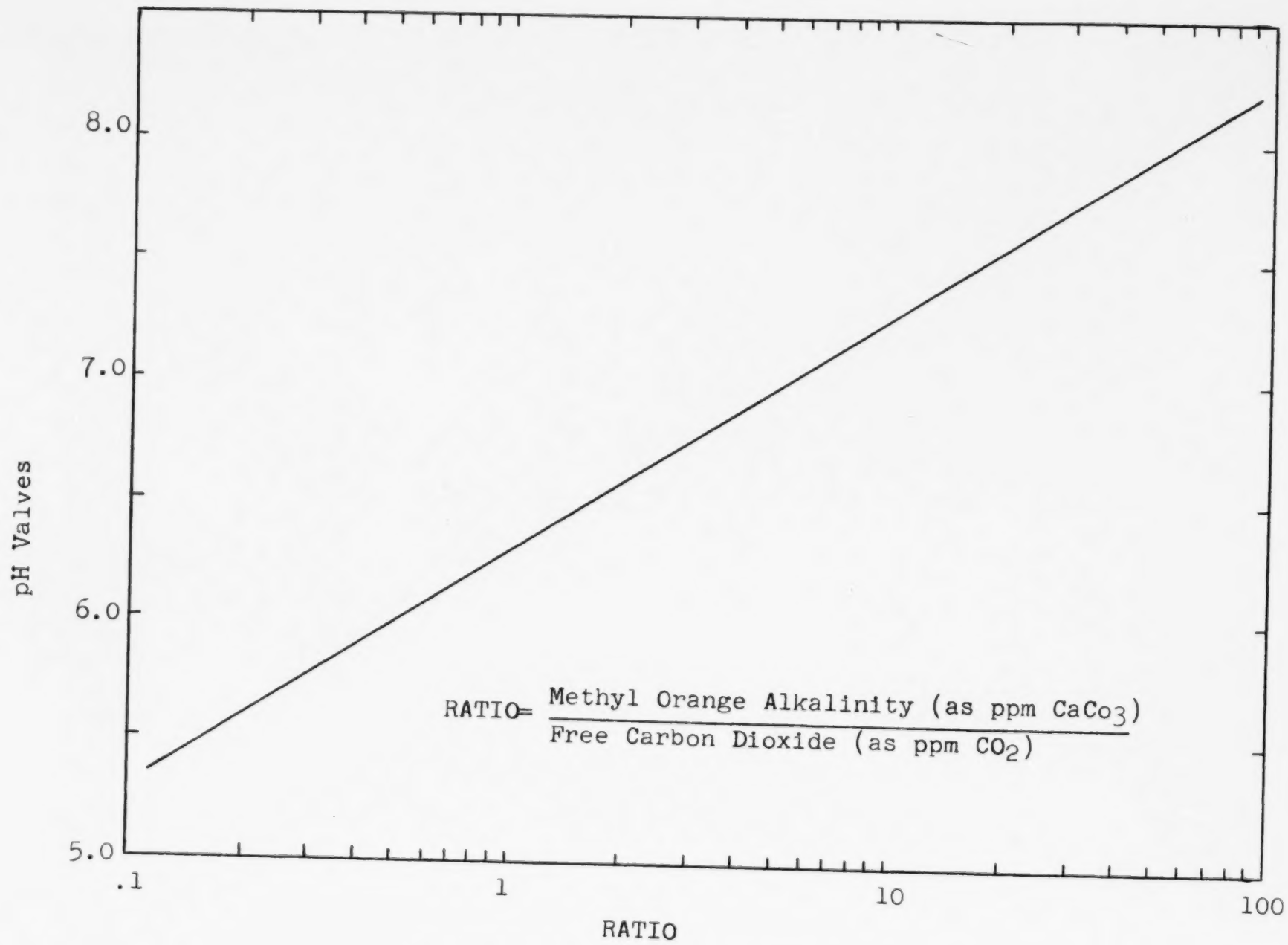
*Methyl Orange Alkalinity (ppm)

**$FeCl_3$ solids demand only used when computing lime and is considered minimum. Many operators use much more to increase the filter rate.


Percentage of Water in Sludge A
Percentage of Solids in Sludge B
Parts per Million of Methyl orange Alkalinity in water C
Percentage of Ferric Chloride for Alkalinity (Liquid Demand) D
Total Percentage of Ferric Chloride Dose E
Percentage of Volatile Matter in Sludge F
Percentage of Ferric Chloride for Volatile (Solid Demand) G

Nomograph for $FeCl_3$ Requirements

Figure 15



Interrelation of Bicarbonate Alkalinity
CO_2 and pH

Figure 16

TABLE 1

VACUUM FILTER PRODUCTION

Type of Pretreatment	Production lb Dry Solids/ft^2/hr
Raw Primary	5
Raw Primary Plus Trickling Filtration	4
Raw Primary Plus Activated Sludge	2.5

The computed equations for vacuum filtration were:

Capital Cost

$$\text{Log (Cost)} = 0.65 - 0.66 \text{ Log (Area)}$$

Cost = Hundreds of dollars/square foot

Area = Hundreds of square feet

Power Cost

Cost = 0.15 (Area)

Cost = cents/hr

Area = square feet

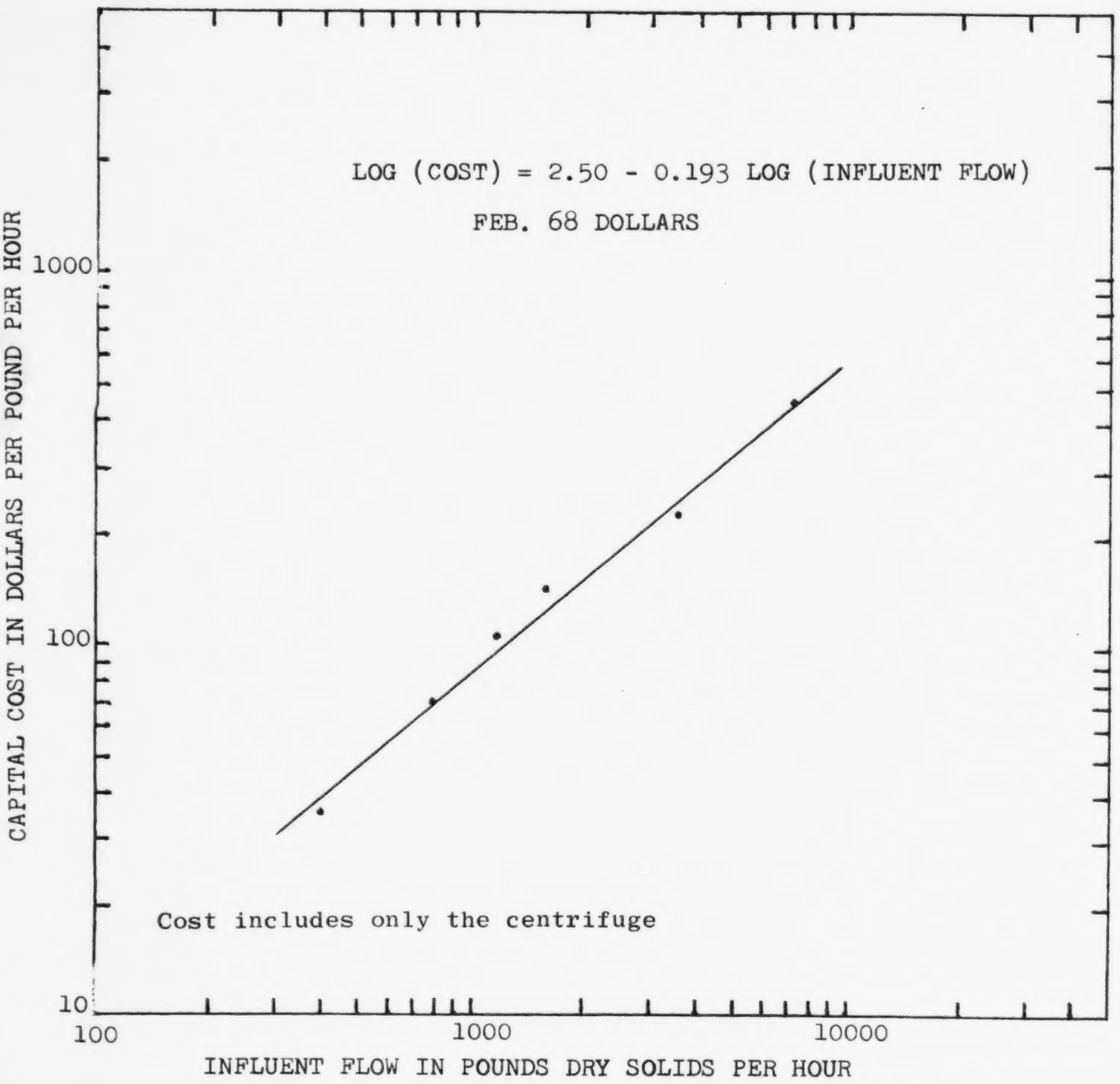
Centrifugation

The capital costs for dewatering by centrifugation are plotted on Figure 17. Only the cost of the centrifuge was considered.

Polymer (polyelectrolytes) costs were based on three types of sludge - that produced from: (1) primary treatment (raw), (2) primary plus trickling filtration and (3) primary plus aeration. These costs are shown on Figures 18-20, respectively. The upper and lower limits indicate the probable range while the solid line indicates the average chemical cost for the various types of sludges.

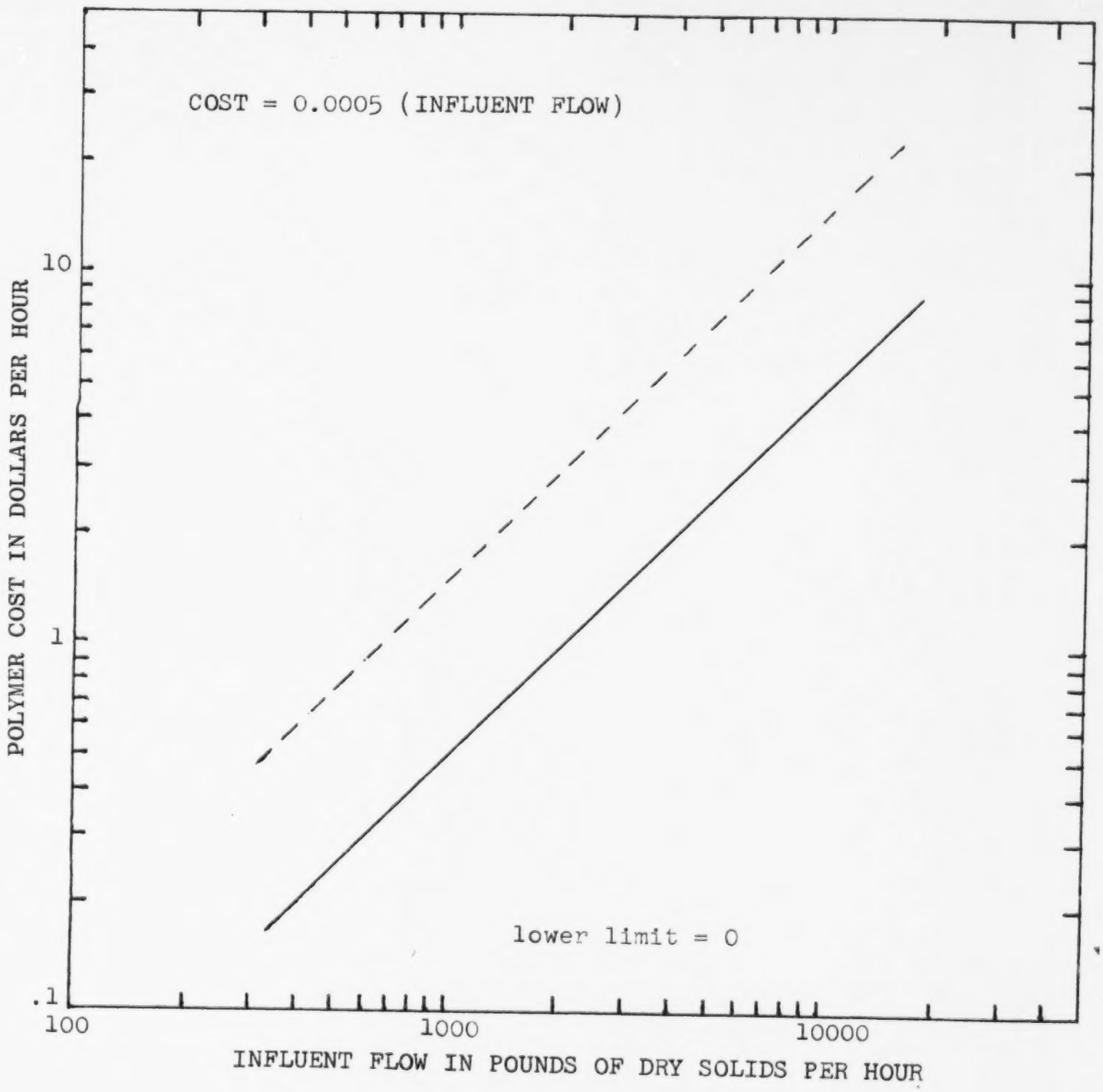
Power costs for centrifuges normally used in sanitary applications run about 90 cents per ton of dry solids (1.5 cents/kwh).

Table 2 gives a good indication of the performance of centrifugal dewatering.



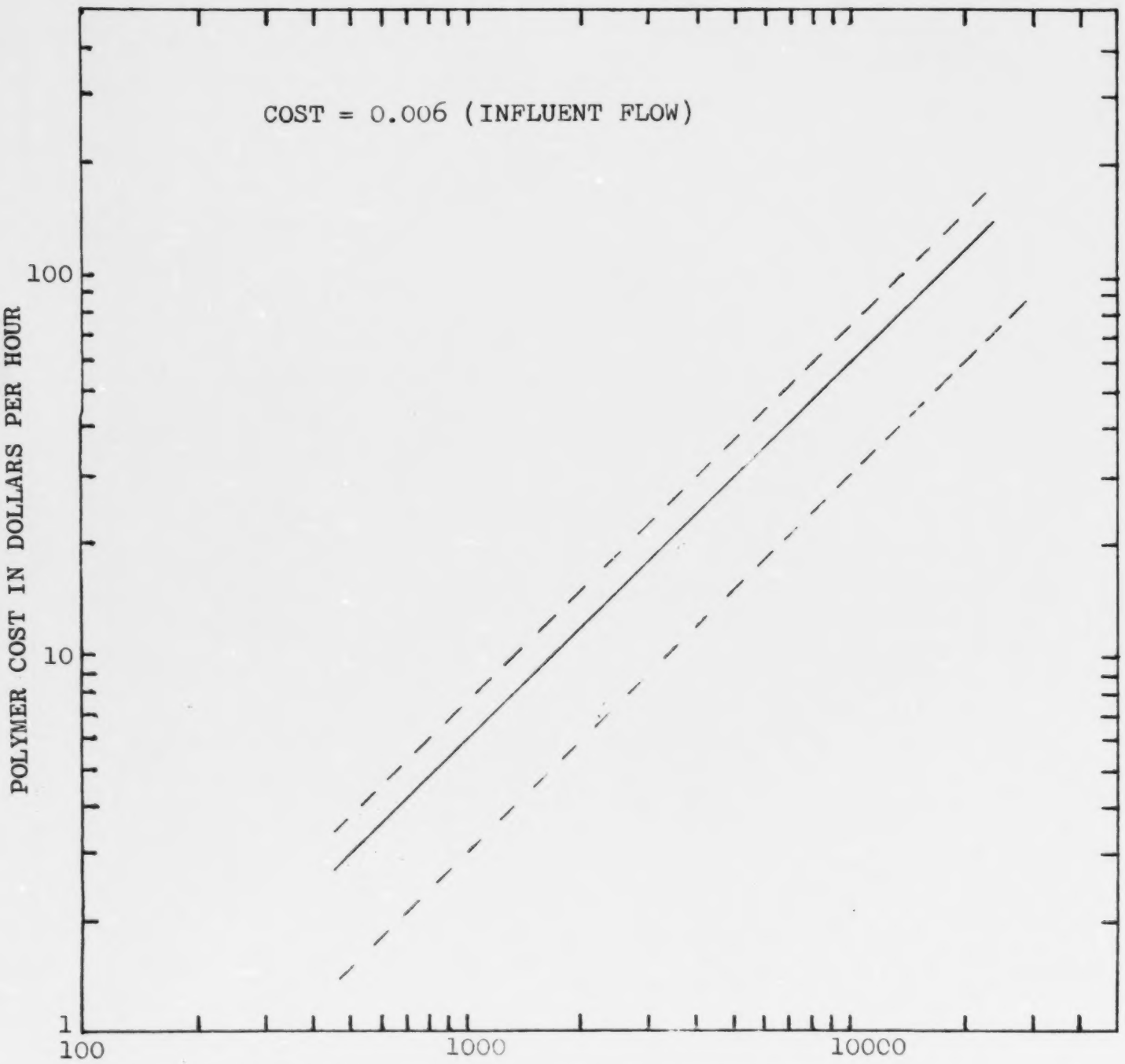
Capital Cost of Centrifugation
Versus Influent Flow to Centrifuge

Figure 17



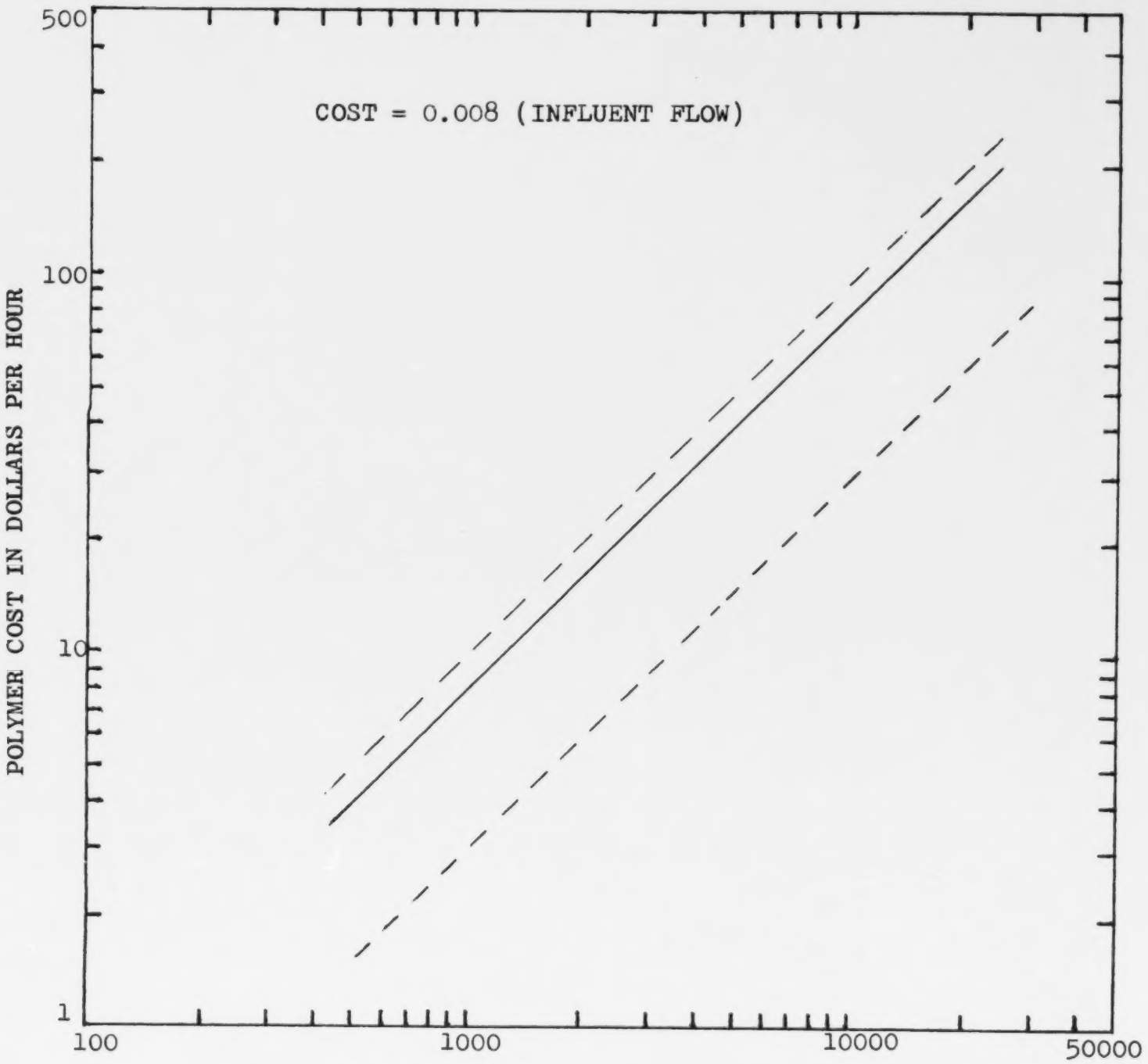
Cost of Polymer For Treatment of Primary Sludge For Dewatering by Centrifugation

Figure 18



Cost of Polymer For Treatment of Primary Plus Trickling Filter Sludge For Dewatering by Centrifugation

Figure 19



Cost of Polymer For Treatment of Primary Plus Activated Sludge For Dewatering by Centrifugation

Figure 20

TABLE 2

SOLIDS RECOVERY BY CENTRIFUGATION

Type of Pretreatment	Percent Recovery (Total Solids - Dry Basis) W/O Chemicals	W/Chemicals
Raw Primary	85-95	90-100
Raw Primary Plus Trickling Filtration	65-85	90-100
Raw Primary Plus Activated Sludge	65-80	90-100

The computed equation for the capital cost of centrifugation was:

$$\text{Log (Cost)} = 2.50 - 0.193 \text{ Log (Influent flow)}$$

Cost = Dollar/lb/hr

Influent flow = lb Dry Solids/hr

The computed equations for the cost of chemicals for dewatering by centrifugation were:

Primary sludge:

$$\text{Cost} = 0.0005 \text{ (Influent flow)}$$

Primary plus trickling filtration sludge:

$$\text{Cost} = 0.006 \text{ (Influent flow)}$$

Primary plus waste activated sludge:

$$\text{Cost} = 0.008 \text{ (Influent flow)}$$

where:

Cost = Dollars

Influent flow = pounds of dry solids per hour

Sludge Drying Beds

Sewage sludge dewatering using sludge drying beds is becoming impractical. Drying beds, either glass covered or open, are constructed with a system of underdrains covered by a layer of graded rock from 12 to 18 inches deep followed by a layer of sand 6 to 12 inches deep. The area of the bed varies to meet individual conditions of sludge quantities and climatic conditions, but is usually figured on 1 to 2 square feet per capita. Dried sludge is removed from the bed by hand labor or mechanical lift devices. Land cost and availability greatly affect the cost of drying beds.

SLUDGE COMBUSTION

The capital costs of fluid bed combustion are shown on Figure 21. As demonstrated on the figure, there is a decrease in the capital cost as the solid content of the feed increases.

The following processes are included in this cost:

- Solids preparation, including comminution and pumping
- Solids dewatering, including centrifugation
- Combustion air supply
- Solids combustion, including conveying, feeding and burning
- Stack gas treatment, including ash removal, gas scrubbing and ash handling

Also included are all electrical and piping requirements.

Operating costs for fluid bed combustion were based on three types of sludges - those produced from (1) primary treatment (raw), (2) primary treatment plus trickling filtration and (3) primary treatment plus aeration. This was done since the dewatering characteristics of sludges are a function of degree of treatment.

The operating costs shown on Figures 22 through 24 include fuel, chemicals and power. Fuel, usually No. 2 oil at 11.5 cents/gal. is used to maintain operating temperatures when the heat value of the burning sludge is inadequate for autogenous burning. Chemicals (polyelectrolytes) are used to control the performance of the dewatering equipment. Power was assumed to be 1.5 cents/kwh. These costs were based on lbs of dry solids entering the reactor and consideration was given to heat recoverable from the sludge. The upper and lower limits give some indication as to the range which may be experienced. The solid line indicates the average cost.

Labor costs will vary considerably depending upon operation, but 0.25 man-hours per hour of operation is generally used. Labor costs were not included in Figure 22 - 24.

The equations computed for capital costs of fluid bed incineration are given below:

With 22% solid feed:

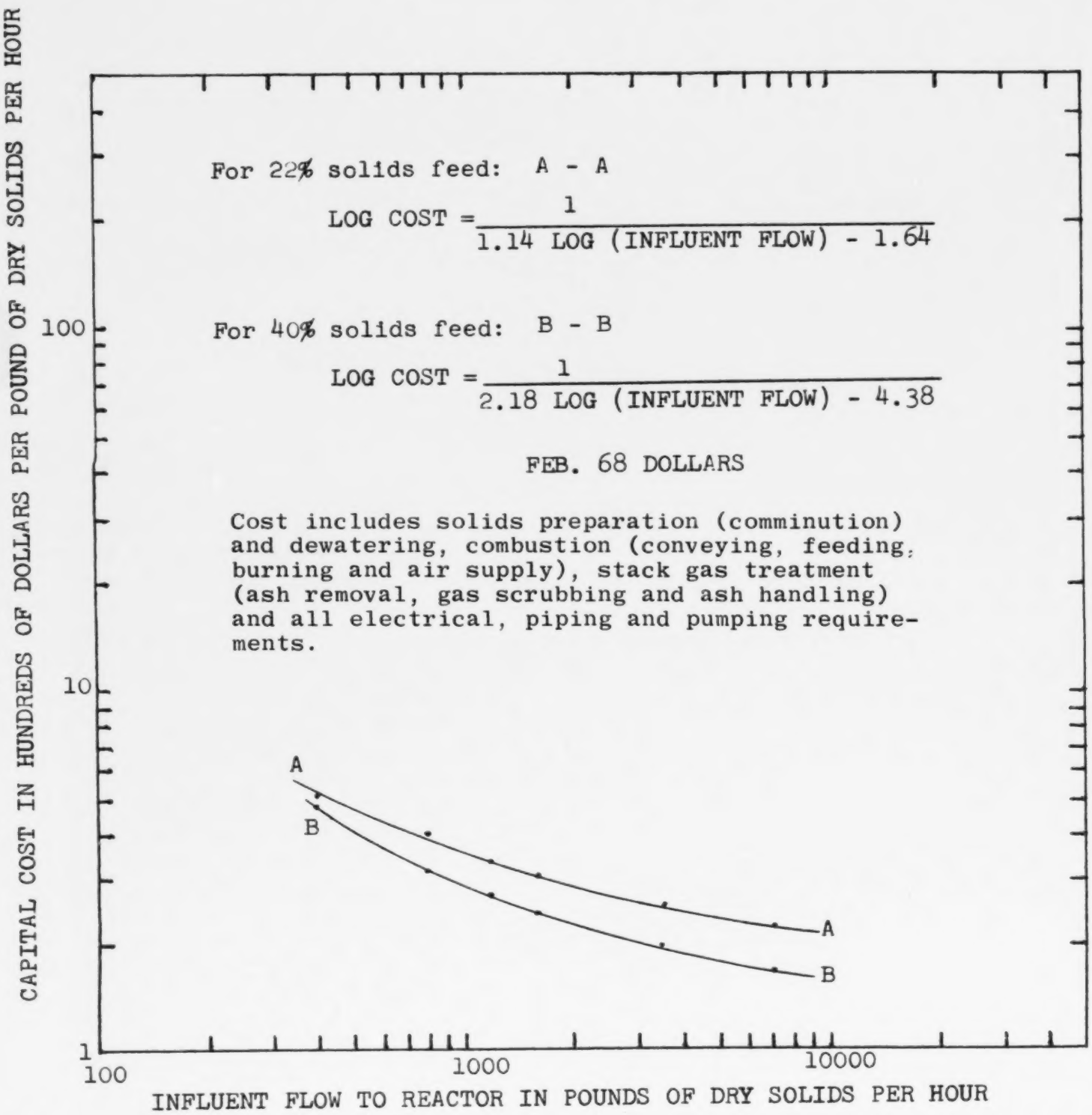
$$\text{Log (Cost)} = \frac{1}{1.14 \text{ Log (Influent flow)} - 1.64}$$

With 40% solid feed:

$$\text{Log (Cost)} = \frac{1}{2.18 \text{ (Log Influent flow)} - 4.38}$$

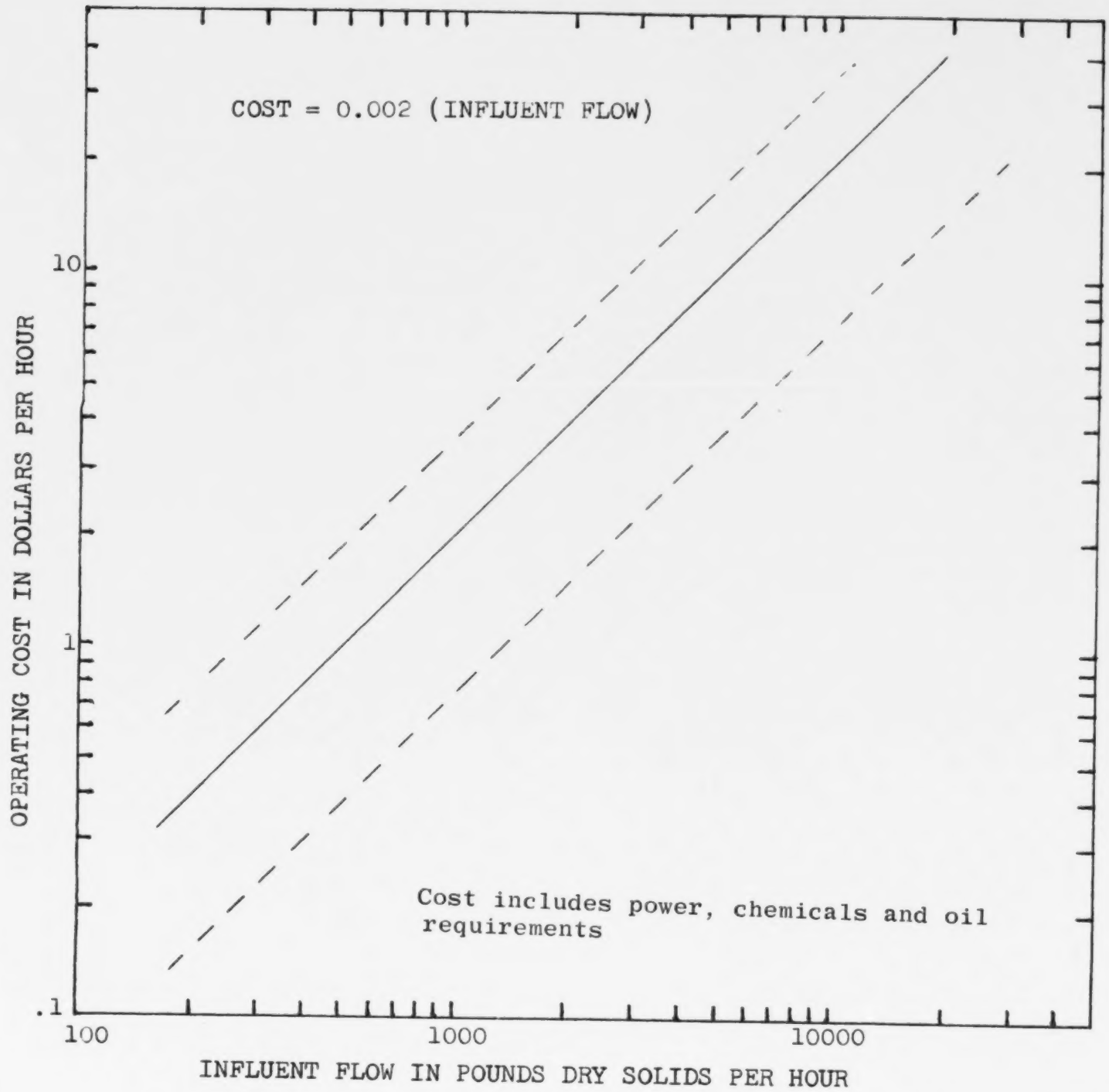
Cost = Hundreds of dollars/lb/hr

Capacity = Lb Dry Solids/hr


For 22% solids feed: A - A
LOG COST = 1 / 1.14 LOG (INFLUENT FLOW) - 1.64
For 40% solids feed: B - B
LOG COST = 1 / 2.18 LOG (INFLUENT FLOW) - 4.38
FEB. 68 DOLLARS
Cost includes solids preparation (comminution) and dewatering, combustion (conveying, feeding, burning and air supply), stack gas treatment (ash removal, gas scrubbing and ash handling) and all electrical, piping and pumping requirements.
CAPITAL COST IN HUNDREDS OF DOLLARS PER POUND OF DRY SOLIDS PER HOUR
100
10
1
A
B
A
B
100
1000
10000
INFLUENT FLOW TO REACTOR IN POUNDS OF DRY SOLIDS PER HOUR

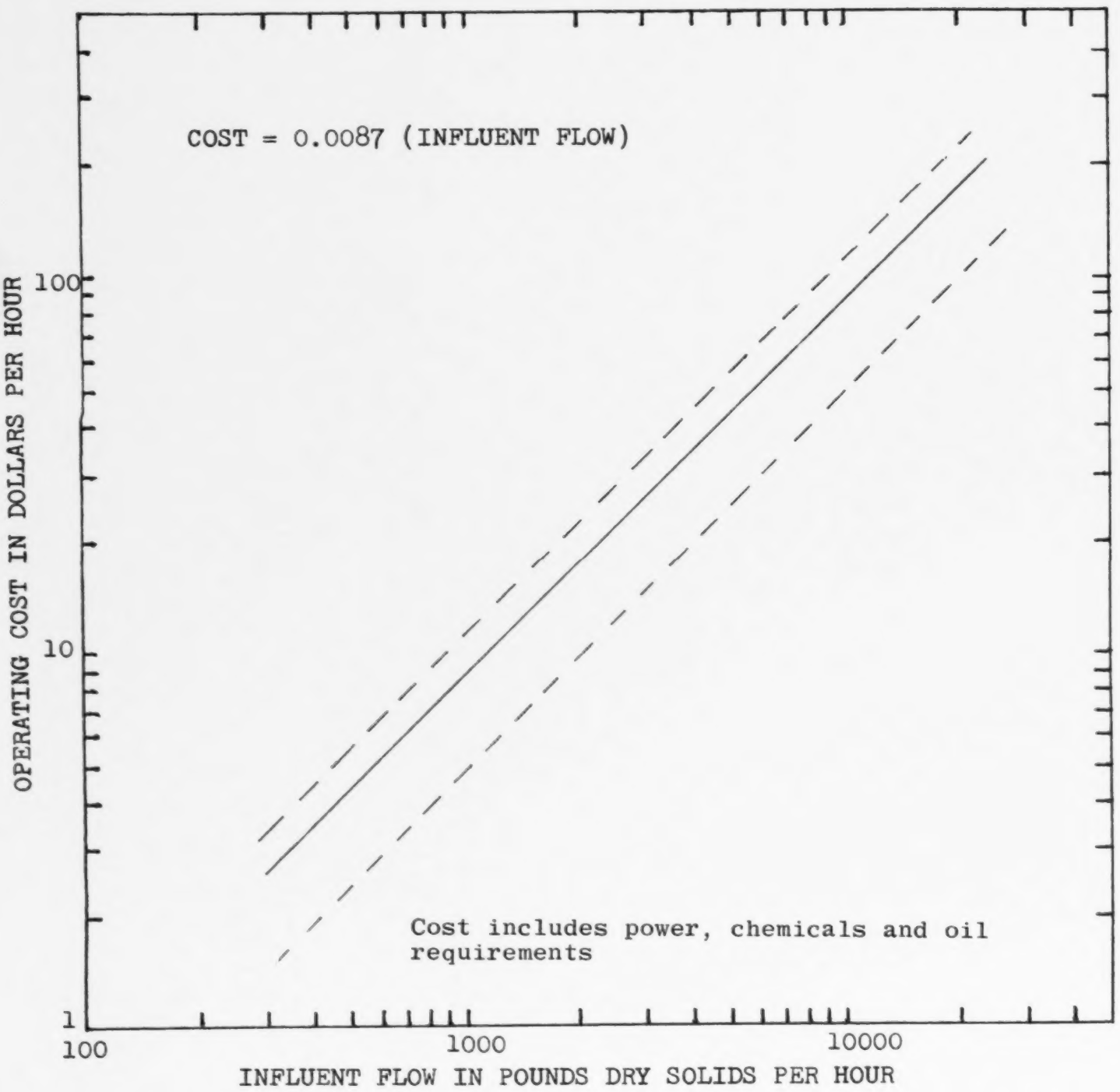
Capital Cost of Fluid Bed Sludge Combustion
Versus Influent Flow to Reactor

Figure 21



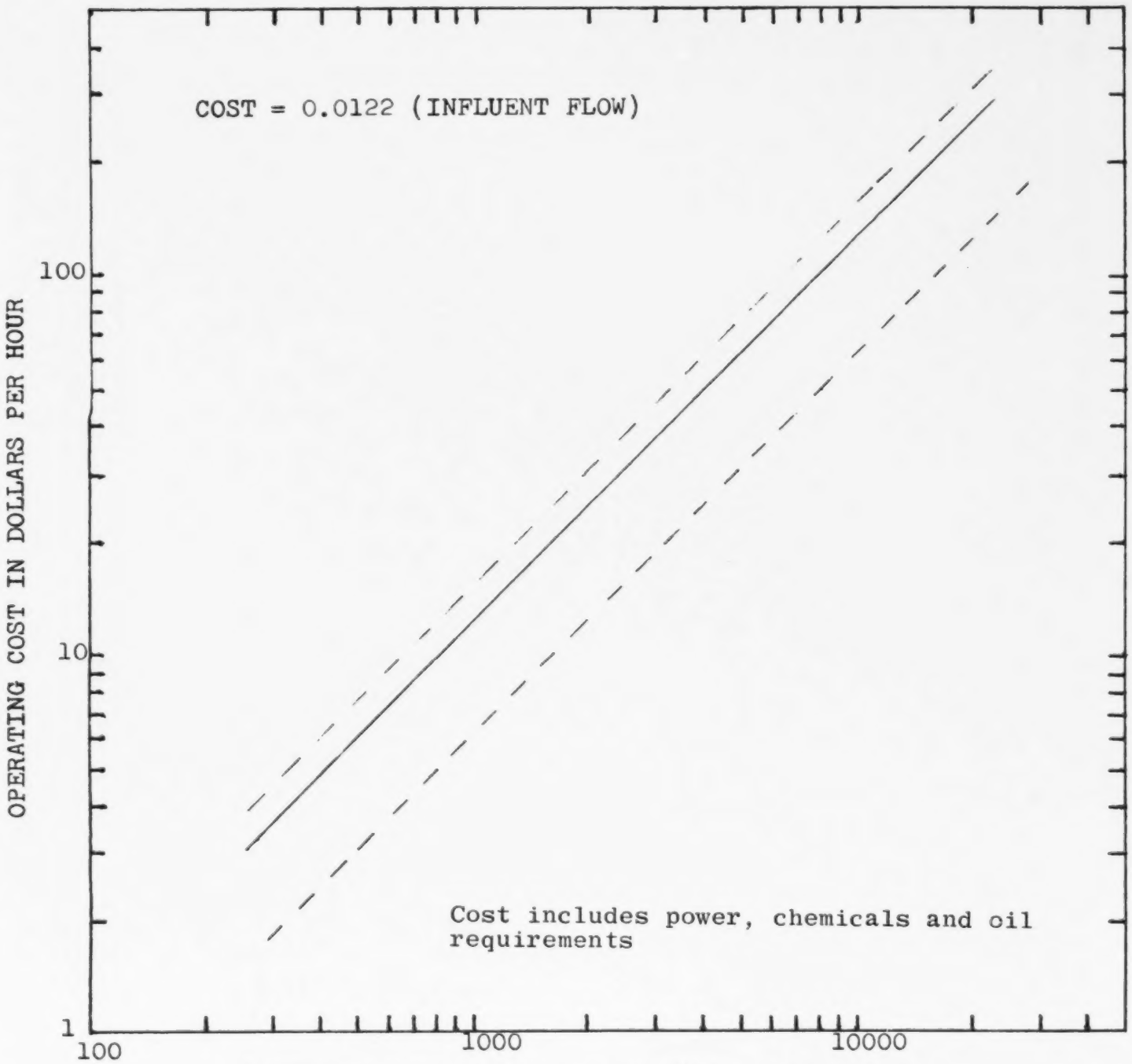
Operating Cost For Combustion of Primary Sludge
Versus Reactor Influent Flow

Figure 22



Operating Cost For Combustion of Primary Plus Trickling Filter Sludge Versus Reactor Influent Flow

Figure 23



Operating Cost For Combustion of Primary
Plus Waste Activated Sludge Versus
Reactor Influent Flow

Figure 24

The equations computed for the operating costs of fluid bed incineration including power, chemicals and oil requirements are given below:

Primary sludge:

$$\text{Cost} = 0.002\ (\text{Influent flow})$$

Primary plus trickling filter sludge:

$$\text{Cost} = 0.0087\ (\text{Influent flow})$$

Primary plus waste activated sludge:

$$\text{Cost} = 0.0122\ (\text{Influent flow})$$

where:

Cost = Dollars/hr

Influent flow = Lb dry solids/hr

NUTRIENT REMOVAL

The comparative costs for phosphorous removal[3] are shown in Table 3. In recent years, significant strides have been made in the basic approaches to phosphate removal. New concepts and arrangements of treatment plant unit processes have reduced the cost and have made it feasible for government and state agencies to consider enforcement of phosphate removal standards.

TABLE 3

COMPARATIVE COSTS FOR PHOSPHOROUS REMOVAL

Method	Added Cost for Phosphorous Removal (cents/1000 gal) Capital	Operating
Phosphate Extraction Process	0	1.0
Activated Sludge Chemicals	1.5	3.0
Tertiary System Chemicals	1.0	6.5
Land Disposal	9.0	3.0
Ion Exchange	1.0	23.0

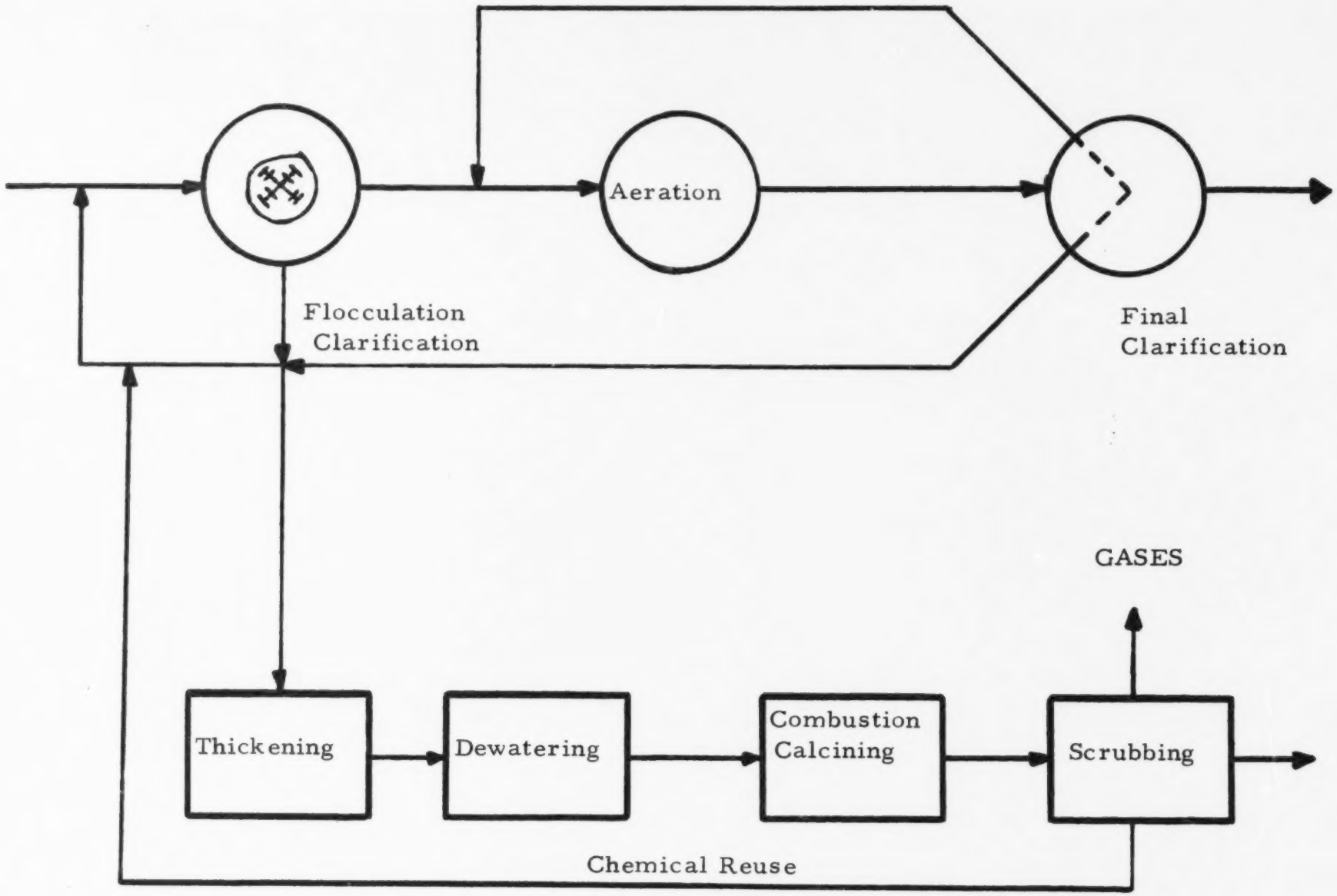
The tertiary system approach consists of utilizing metallic coagulants in conjunction with polymers. Removal is based on fixed chemical stoichiometrics since the majority of the poly- and metaphosphates are hydrolized in aeration basins and appear as soluble orthophosphate in the tertiary system.

The activated sludge method consists of the addition of alum to the aeration basin. Removal is realized by chemical combination and incorporation of phosphorous in the activated sludge cell.

The phosphate extraction process (PEP) is a Dorr-Oliver, proprietary approach. The complete PEP system, as it is presently being marketed, is shown on Figure 25. Except for the recirculation of chemical sewage floc around the primary clarifier and the use of flocculating clarifier, there is essentially no difference from conventional treatment flowsheets.

The PEP approach takes advantage of low ratios of soluble to total phosphate in the primary clarifier. A coagulant, such as lime, is added to the primary clarifier where gross removal of phosphorous is efficiently completed by adsorption and settling. Residual phosphorous is then scavenged by the activated sludge culture.

The PEP process operates at a much lower chemical dosage than other tertiary systems. There are two reasons for this: (1) lime dosing in the



Flow Diagram For Phosphate Removal

Figure 25

primary clarifier results in the extraction of that portion of the phosphate (60-70%) which is easiest to remove and (2) recirculation of chemical sewage sludge around the primary clarifier results in an increased chemical efficiency (100-150%). The flocculator-clarifier step removes 60-70% of the BOD because of the increased chemical efficiency which results in a $10/MG (1 cent/1000 gal.) savings in secondary treatment and sludge handling facilities. Consequently, while the PEP approach runs about 2 cents/1000 gal. for operating and capital costs, the 1 cent/1000 gal. savings realized from high BOD removal across the primary step results in a net added cost for phosphorous removal of about 1 cent/1000 gal. which is essentially operating cost.

For plants incorporating the fluid bed sludge combustion system, there is a capability for lime recovery for chemical reuse. However, this is not economically rewarding for plants utilizing small quantities of chemicals. For larger plants, lime recovery could drop the cost of phosphorous removal to 0.5 cents/1000 gal.

The PEP approach removes about 80% of the phosphorous coming into the plant. By adding a tertiary step, 99% removal can be realized without affecting PEP's relative economic attractiveness.

TERTIARY TREATMENT

Sand Filtration

Tertiary treatment by sand filtration is presented on the basis of both small and large plants. The installed capital and operating costs shown on Figures 26-27 are appropriate for plants as large as 100,000 GPD and include rapid sand filtration plus chlorination. The equations computed were:

Capital Cost

$$\text{Log (Cost)} = 0.631 \text{ Log (Influent flow)} + 0.305$$

Cost = Thousands of dollars

Influent flow = Thousands of gallons per day

Operating Cost

$$\text{Log (Cost)} = \frac{1}{1.763 - 0.575 \text{ Log (Influent flow)}}$$

Cost = Hundreds of dollars per year

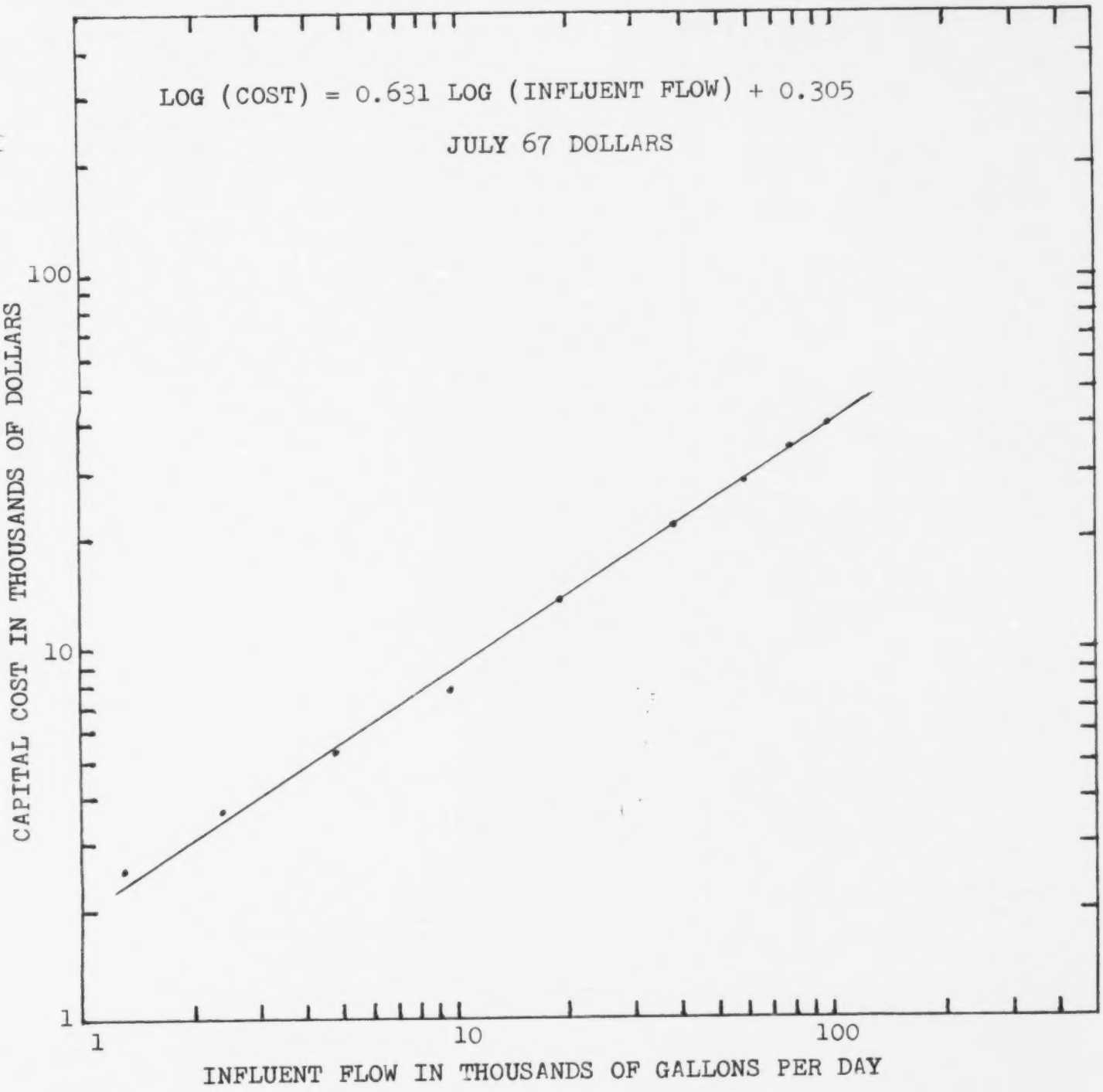
Influent flow = Thousands of gallons per day

The total installed treatment cost on Figure 28[4] which is pertinent for plants between 1 and 100 MGD, was derived from a study of thirty water treatment plants. Filtration is preceded by coagulation and settling. This cost includes capital investment for 30 years at 4% interest (fixed annual cost of 7.78% of plant investment adjusted to 1964), labor, power, chemicals, maintenance and repair, heating of buildings, and other miscellaneous costs. It assumes that the plant is operating at full capacity ($\bar{U} = 1.0$ in Koenig's paper) and that the cost of water filtration equals that for filtration of secondary effluent. This latter assumption is reasonable since the equipment involved is comparable. The 10 and 90 percentiles drawn on Figure 28 were based on factors of 0.76 and 1.32, respectively.

The equation of the curve presented in Koenig's paper may be computed as:

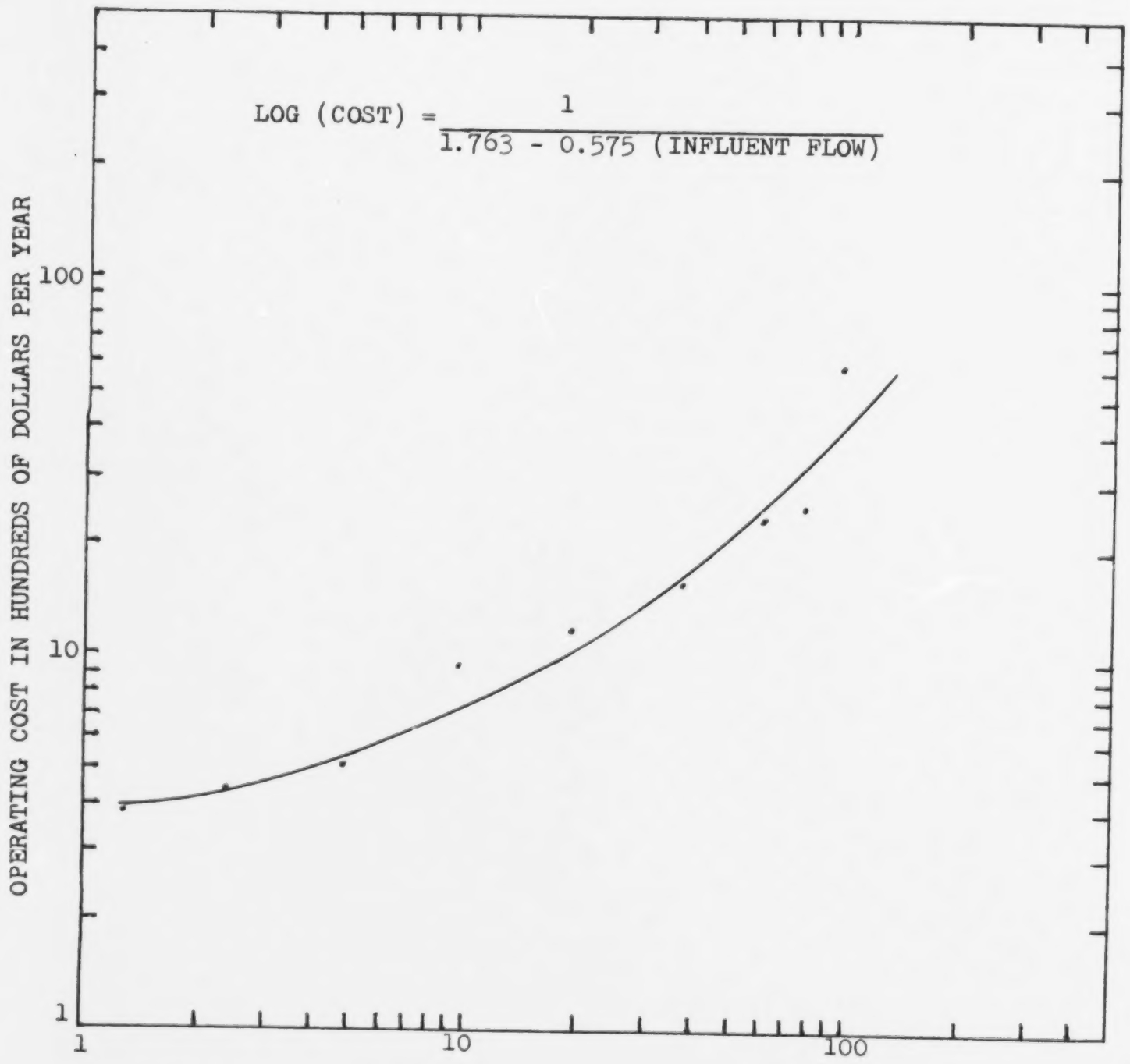
$$\text{Log (Cost)} = 1.176 - 0.336 \text{ Log (MGD)}$$

Cost = cents/1000 gal.



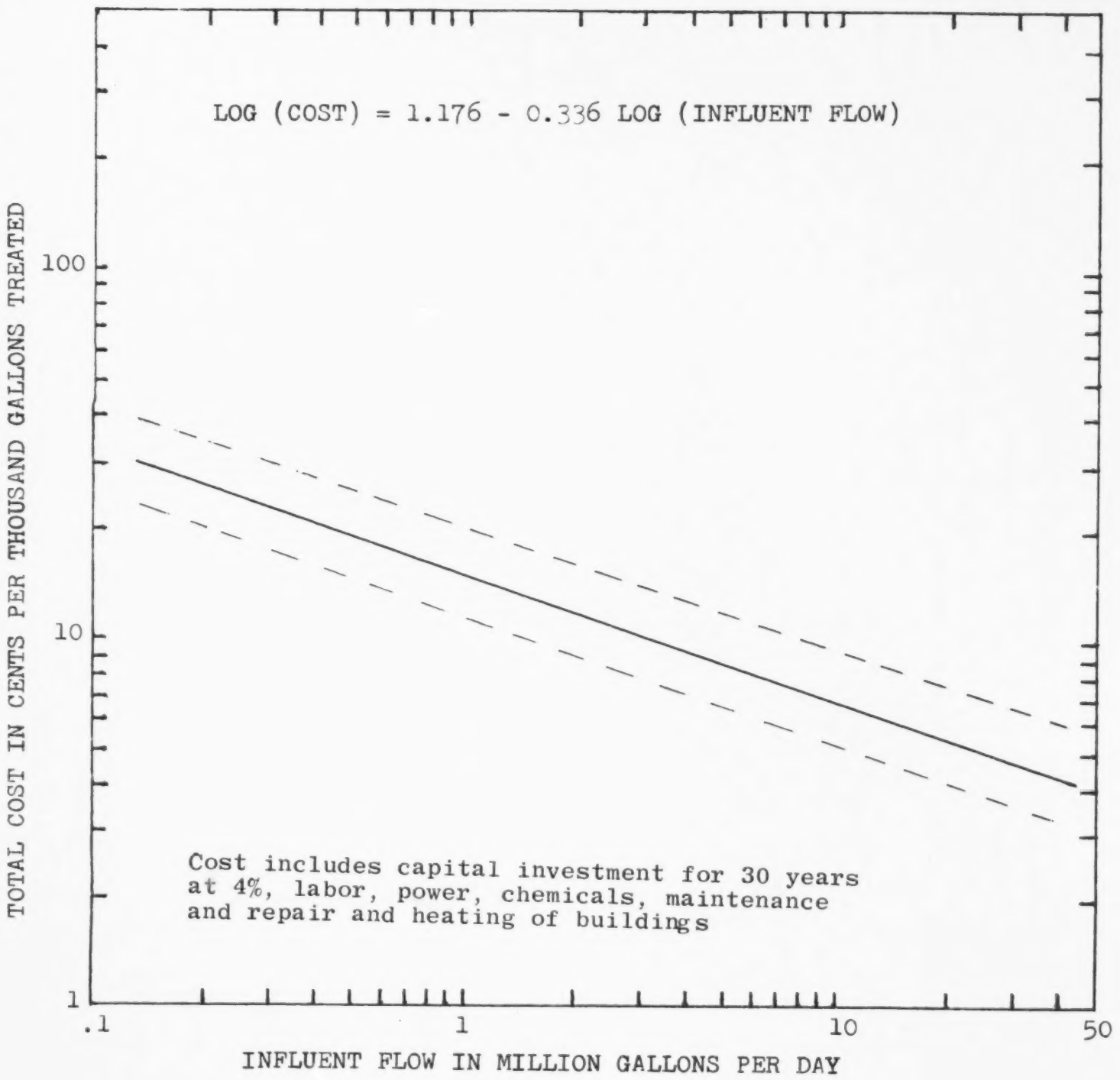
Capital Cost For Tertiary Treatment by Rapid Sand Filtration Plus Chlorination Versus Influent Flow

Figure 26



Operating Cost For Tertiary Treatment
by Rapid Sand Filtration Plus
Chlorination Versus Influent Flow

Figure 27


LOG (COST) = 1.176 - 0.336 LOG (INFLUENT FLOW)
TOTAL COST IN CENTS PER THOUSAND GALLONS TREATED
100
10
1
.1
1
10
50
Cost includes capital investment for 30 years at 4%, labor, power, chemicals, maintenance and repair and heating of buildings
INFLUENT FLOW IN MILLION GALLONS PER DAY

Total Cost of Tertiary Treatment by Coagulation and Settling Followed by Rapid Sand Filtration Versus Influent Flow

Figure 28

Performance of sand filters depends largely on the processes which precede filtration. A properly operated sand filter preceded by processes such as coagulation and sedimentation, can remove most of the suspended solids, color, turbidity and bacteria. Rapid sand filters are capable of bacterial removals of 90-99% when the bacterial loading is reasonably low, but adequate chlorination should follow filtration under all conditions of operation.

Carbon Adsorption

Figure 29 summarizes the total treatment cost in cents/1000 gal. for tertiary treatment by powdered activated carbon[5]. These estimates were based on a two-stage countercurrent adsorption process with a carbon dosage of 300 mg/1, carbon cost of 7 cents/lb, power 1 cent/kwh, steam 1 dollar/million Btu, amortization for 20 years at 4% interest, maintenance at 3% fixed capital investment, polyelectrolytes at 1 dollar/lb, carbon loss at 5% per cycle and an average secondary effluent COD of 40 mg/1. The COD of the tertiary effluent averaged 5 mg/1. The flowsheet assumed is shown on Figure 30.

The equations representing treatment costs for tertiary treatment by activated carbon were computed as given below:

Capital Cost:

$$\text{Log (Cost)} = 0.839 - 0.495 \text{ Log (Influent flow)}$$

Operating Cost:

$$\text{Log (Cost)} = \frac{1}{0.45 \text{ Log (Influent flow)} + 1.06}$$

Total Cost:

$$\text{Log (Cost)} = \frac{1}{0.396 \text{ Log (Influent flow)} + 0.83}$$

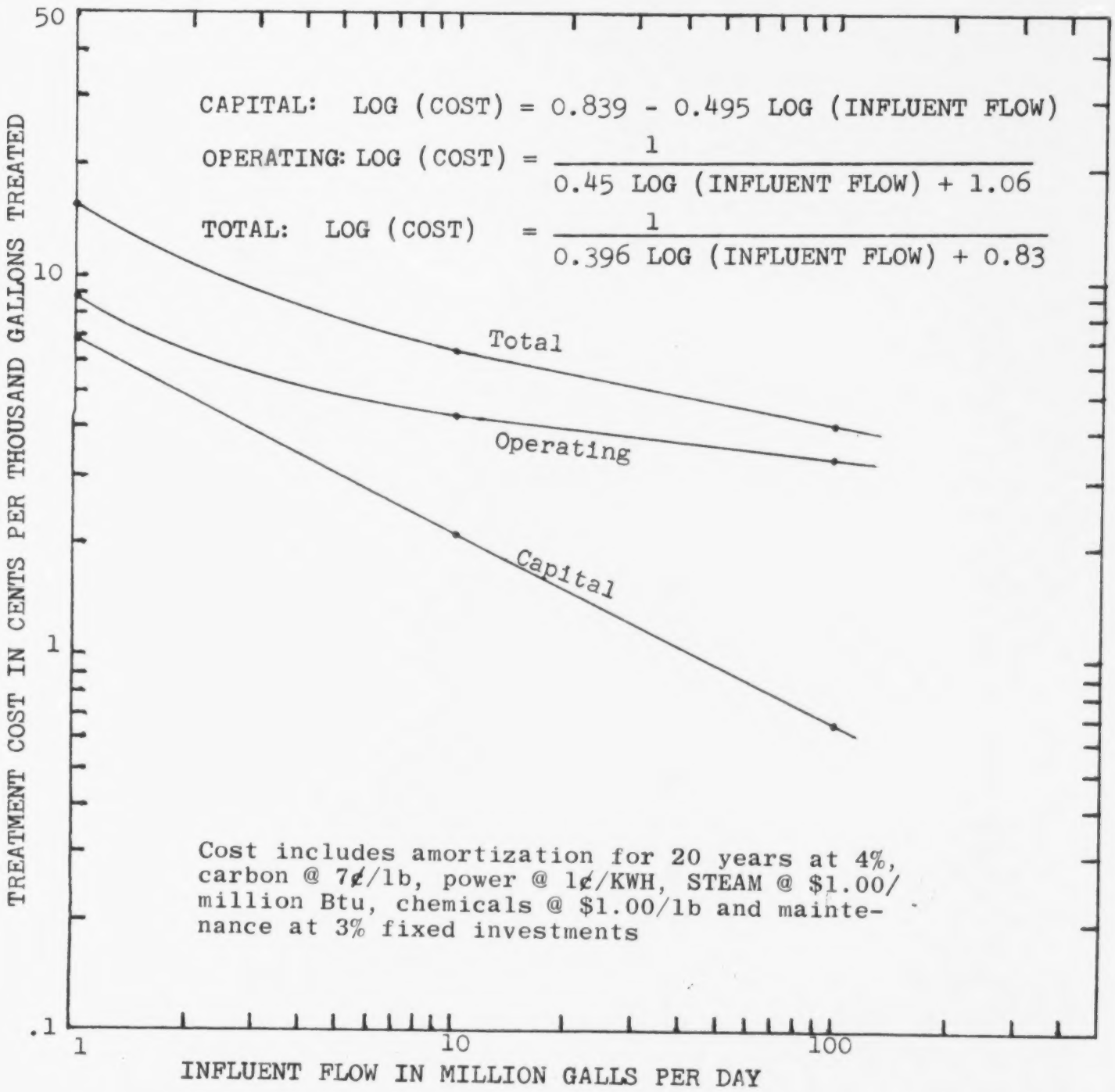
where:

Cost = Cents per thousand gallons

Influent flow = Million gallons per day

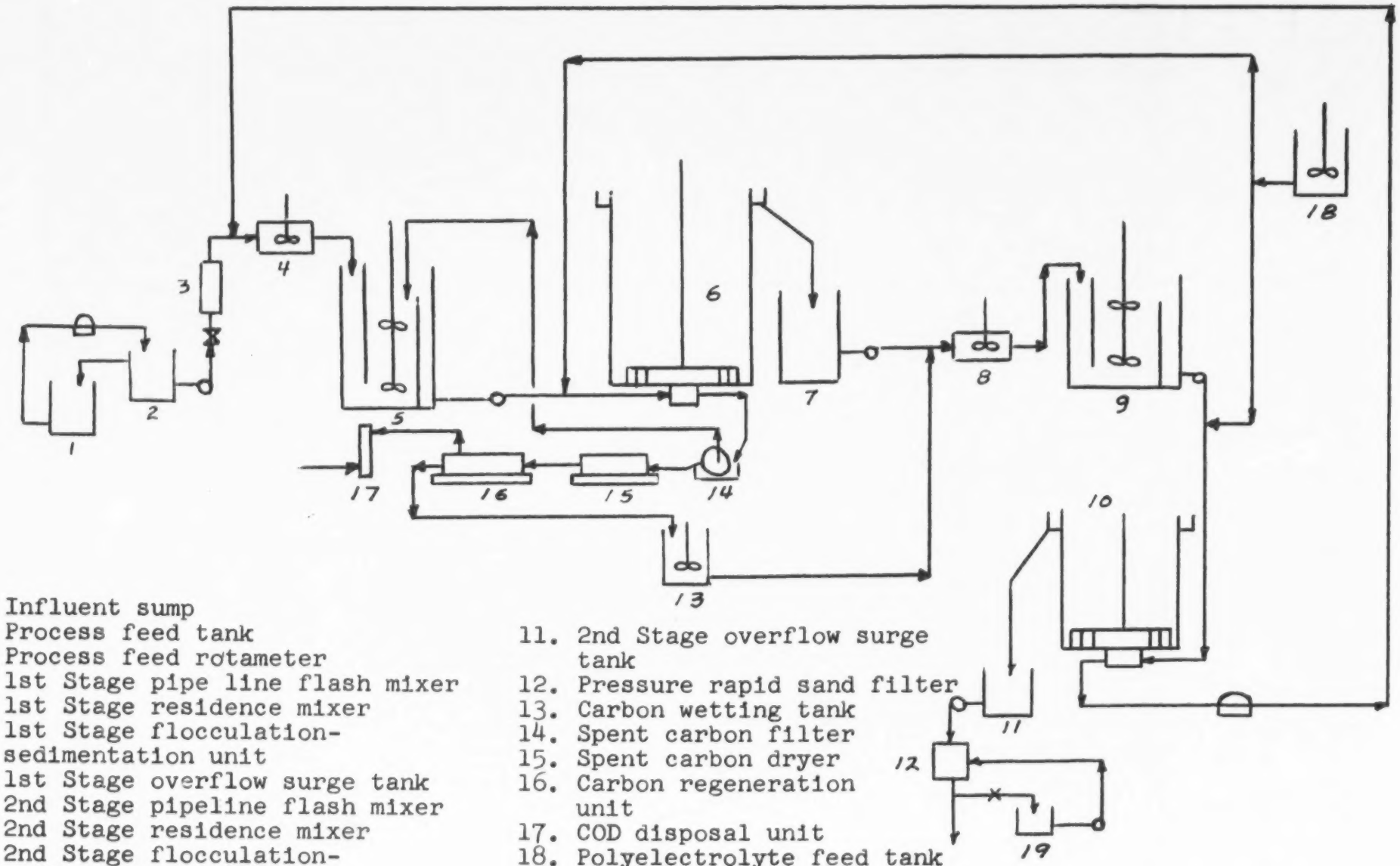
Membrane Ultrafiltration

Figures 31-32 show the total installed capital and operating costs for complete treatment by membrane systems which would replace conventional primary and secondary processes. The operating costs shown include power, operating and maintenance labor and equipment replacement. System component production has not been optimized as yet therefore the information given will change substantially as the art is developed and large scale production is realized. The equations representing present economic data were computed as follows:


50
10
1
.1
1
10
100
CAPITAL: LOG (COST) = 0.839 - 0.495 LOG (INFLUENT FLOW)
OPERATING: LOG (COST) = 1 / 0.45 LOG (INFLUENT FLOW) + 1.06
TOTAL: LOG (COST) = 1 / 0.396 LOG (INFLUENT FLOW) + 0.83
Total
Operating
Capital
Cost includes amortization for 20 years at 4%, carbon @ 7¢/1b, power @ 1¢/KWH, STEAM @ $1.00/ million Btu, chemicals @ $1.00/1b and maintenance at 3% fixed investments
TREATMENT COST IN CENTS PER THOUSAND GALLONS TREATED
INFLUENT FLOW IN MILLION GALLS PER DAY

Tertiary Treatment Costs by Activated Carbon
Versus Influent Flow

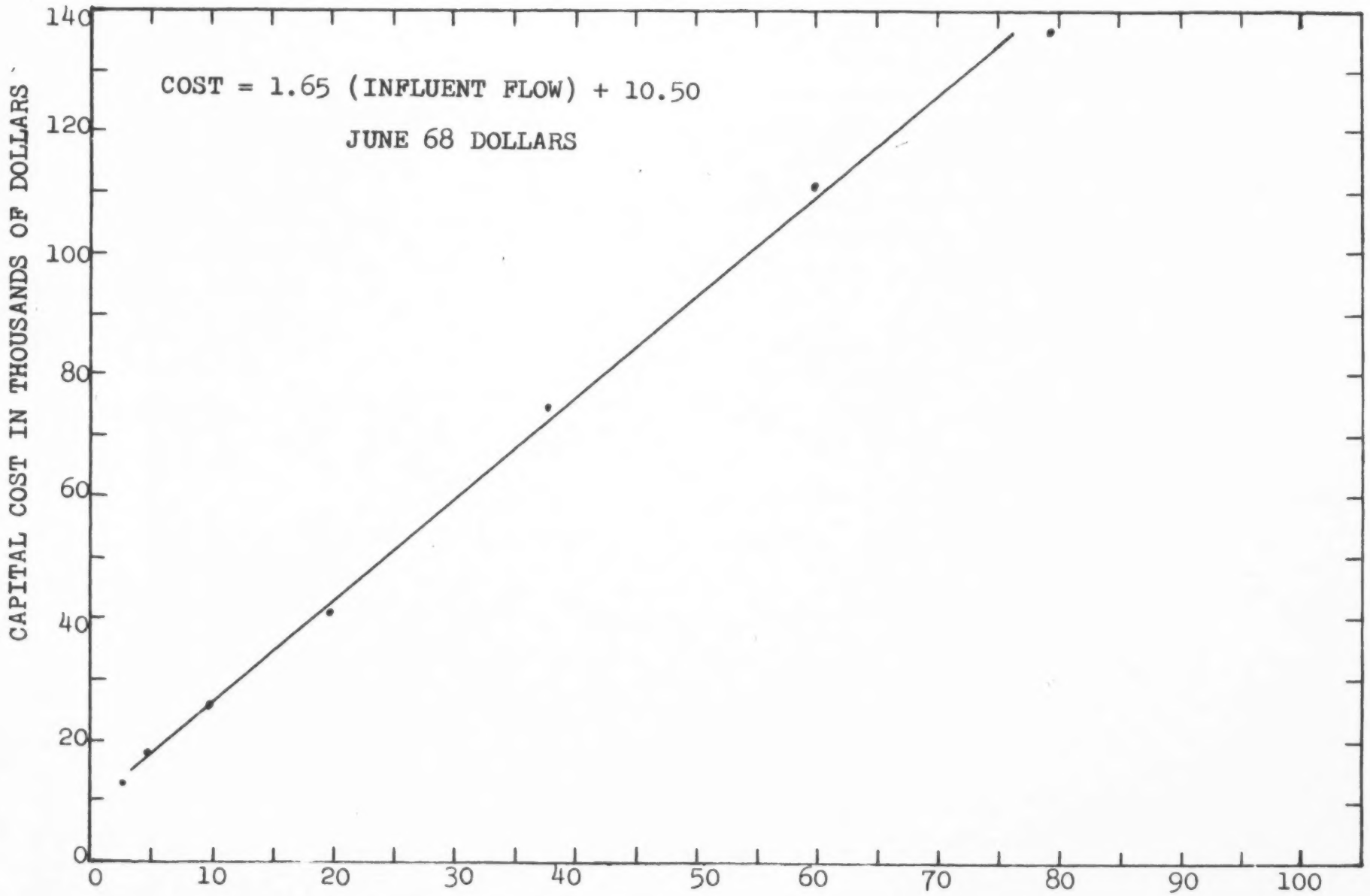
Figure 29



1. Influent sump
2. Process feed tank
3. Process feed rotameter
4. 1st Stage pipe line flash mixer
5. 1st Stage residence mixer
6. 1st Stage flocculation-sedimentation unit
7. 1st Stage overflow surge tank
8. 2nd Stage pipeline flash mixer
9. 2nd Stage residence mixer
10. 2nd Stage flocculation-sedimentation unit
11. 2nd Stage overflow surge tank
12. Pressure rapid sand filter
13. Carbon wetting tank
14. Spent carbon filter
15. Spent carbon dryer
16. Carbon regeneration unit
17. COD disposal unit
18. Polyelectrolyte feed tank
19. Sand filter back wash tank

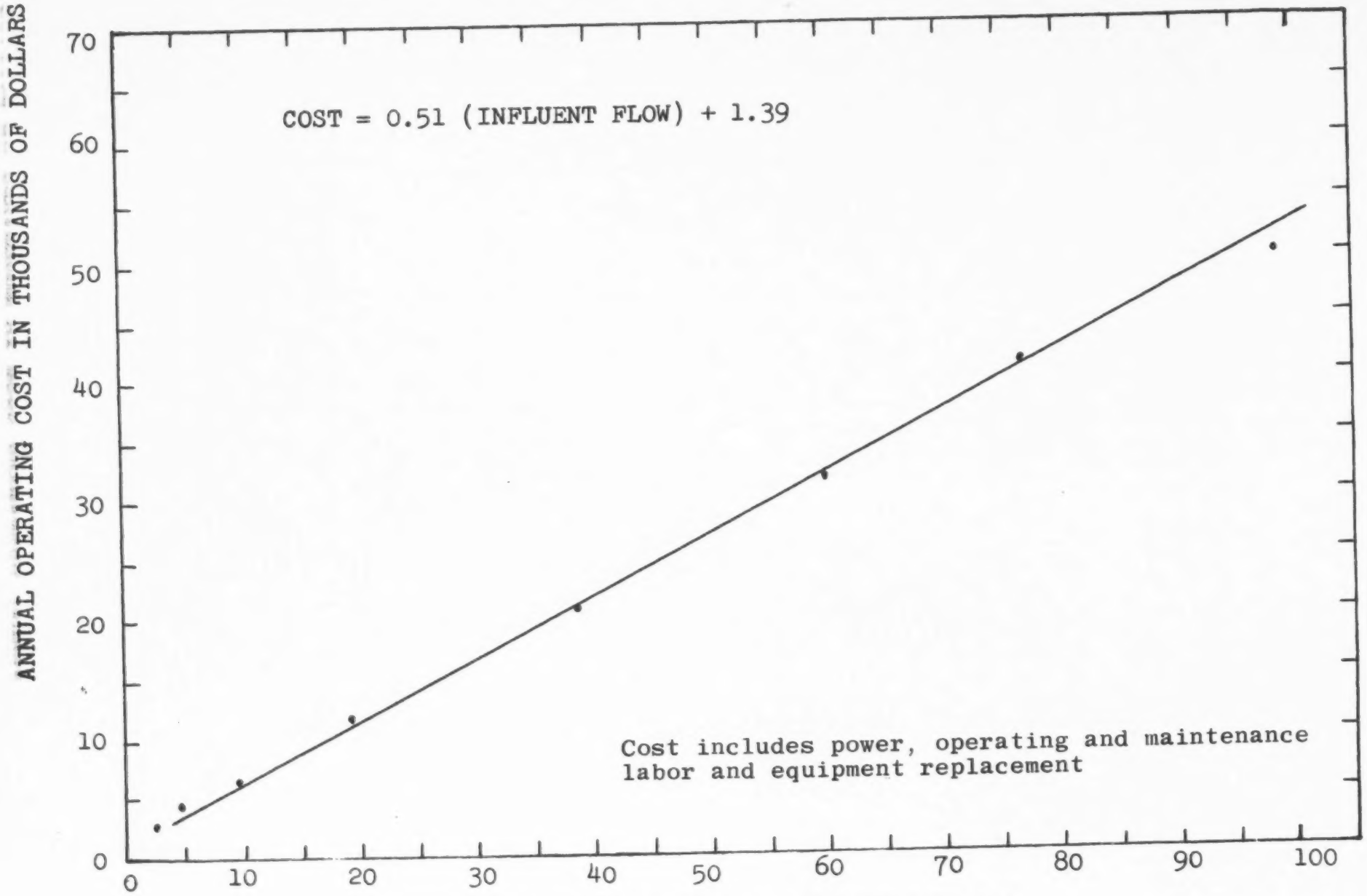
Pilot Plant Flow Sheet

Figure 30



Capital Cost of Complete Treatment by Membrane Ultrafiltration Versus Influent Flow

Figure 31



Annual Operating Cost of Complete
Treatment by Membrane Ultrafiltration
Versus Influent Flow

Figure 32

Capital Cost:

Cost = 1.65 (Influent flow) + 10.5

Cost = Thousands of dollars

Influent flow = Thousands of gallons per day

Operating Cost:

Cost = 0.51 (Influent flow) + 1.39

Cost = Thousands of dollars per year

Influent flow = Thousands of gallons per day

"Complete treatment" provided by membrane systems produces an effluent which is equivalent or better than that from conventional primary plus secondary treatment. Membrane "diffusate" is a high quality water containing no suspended solids and a BOD of 0-20 mg/l. Coliform content is very low, but dependent upon "membrane integrity," a term used to describe the physical condition of the membrane itself.

PACKAGE SEWAGE TREATMENT

The information provided was based on a Dorr-Oliver market study carried on during 1967.

In the independent market study conducted during the first part of 1967 by Dorr-Oliver, it is interesting to note the growth of the package type sewage treatment plant. Ohio is generally considered to be the pioneer state for the package type unit. In 1953, there were only seven plants in operation in that state. It was estimated that in 1955, there were only twenty plants in operation nationwide. By 1967, there were between 6000-7000 plants in operation. Of the total, Ohio alone accounted for over 3000 installations. Florida had over 1000 plants and New Jersey over 300. It was estimated that the growth rate was 12-14% per year in the package sewage treatment field. With the amount of package type plants growing in number each year, this type of installation must be given serious consideration in any study involving cost of waste water treatment systems.

The Dorr-Oliver market study, based on a survey of states nationwide as well as equipment manufacturers data, indicated that the average selling price of the package plant was about $13,000. The majority of plants were of the extended aeration or contact stabilization type. Of the 30 states responding to the market study questionnaire, 63% indicated that chlorination of the effluent was a full-time requirement while the remaining 37% authorized part-time use of chlorine.

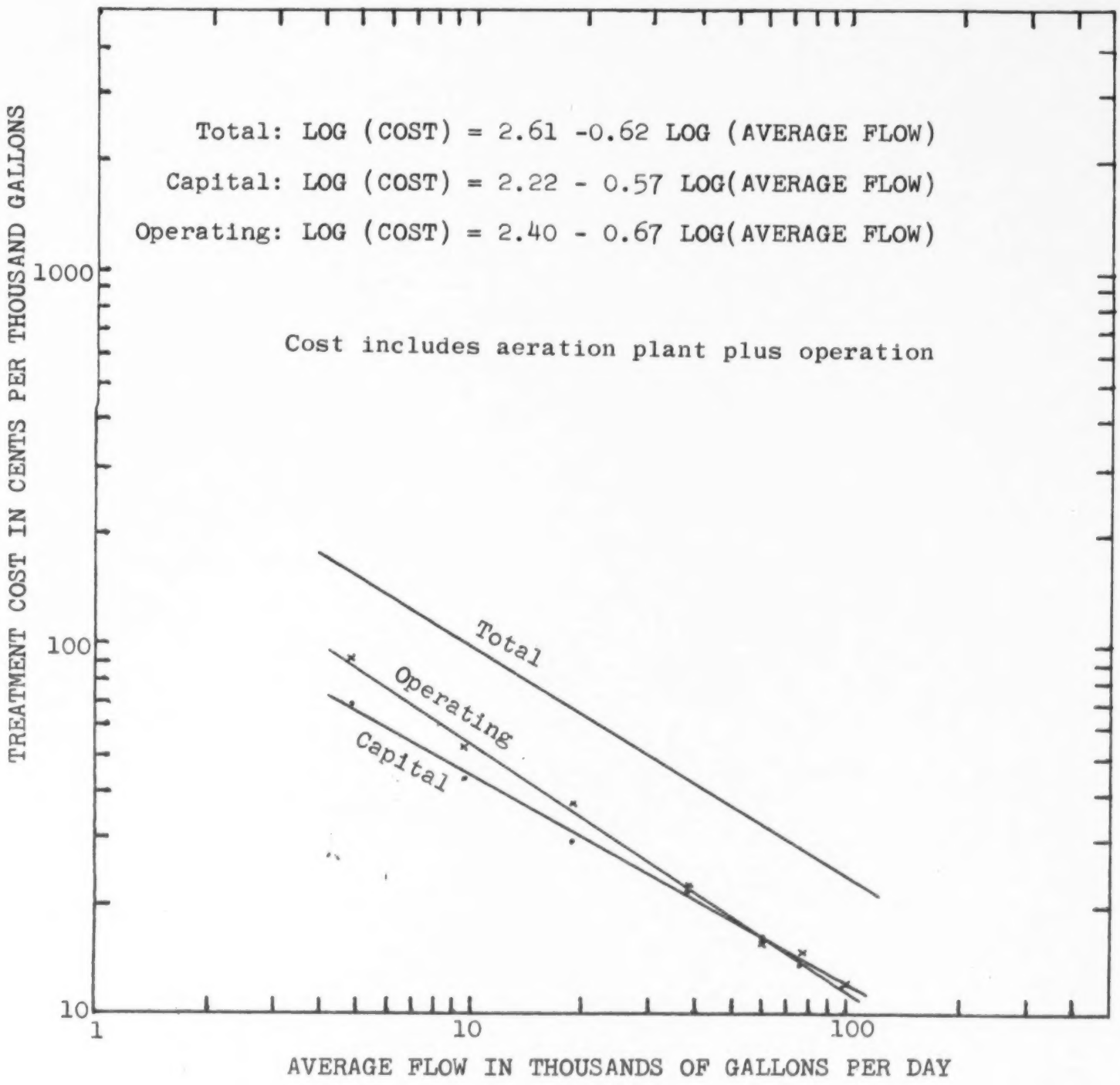
Table 4 presents data "now thought to be realistic" with respect to performance of package units.

TABLE 4

PERFORMANCE OF PACKAGE UNITS

	Extended Aeration	Contact Stabilization
Effluent SS	17-47 mg/1	10-60 mg/1
SS Reduction	65-91%	67-87%
Effluent BOD	6-60 mg/1	10-100 mg/1
BOD Reduction	75-95%	67-93%

The costs of conventional package sewage treatment by extended aeration shown on Figure 33 were based on the following criteria: (1) capital cost amortized at 7.5% total installed cost, (2) labor at 3 dollars/day, (3) power at 1.5 cents/kwh and (4) maintenance at 3.5% mechanical equipment cost.



Treatment Cost of Package Sewage Treatment
by Extended Aeration

Figure 33

Treatment costs for conventional plus tertiary treatment are shown on Figure 34. Included are the costs of the aeration plant from Figure 33, sand filters, chlorinator and housing, erection and the building. Operating costs include power, labor, chlorine and maintenance. The additional tertiary step produces an effluent with a total suspended solids of less than 5 mg/l and a BOD removal of 95-98%.

The computed equations for the cost of package treatment are given below:

Conventional Treatment:

Capital: Log (Cost) = 2.22 - 0.57 Log (Average flow)

Operating: Log (Cost) = 2.40 - 0.67 Log (Average flow)

Total: Log (Cost) = 2.61 - 0.62 Log (Average flow)

Conventional Plus Tertiary Treatment:

Capital: Log (Cost) = 2.26 - 0.473 Log (Average flow)

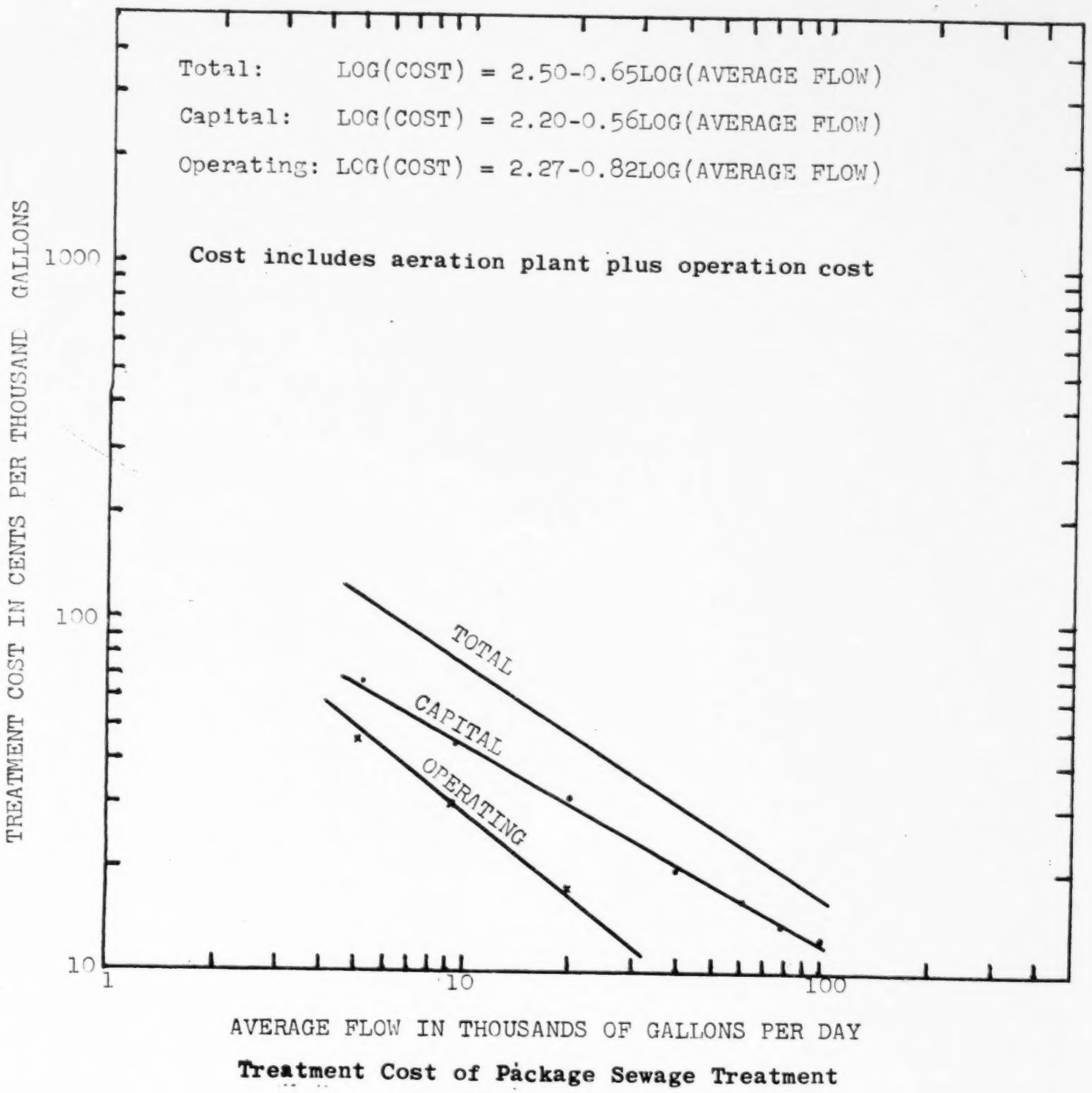
Operating: Log (Cost) = 2.33 - 0.625 Log (Average flow)

Total: Log (Cost) = 2.58 - 0.53 Log (Average flow)

where:

Cost = Cents per thousand gallons

Average flow = Thousands of gallons per day



Treatment Cost of Package Sewage Treatment by Extended Aeration

Figure 34

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2. Genter, A. L., "Computing Coagulant Requirements in Sludge Conditioning," Transactions of American Society of Civil Engineers, 111, 641 (1964).

3. Nesbitt, J. B., "Removal of Phosphorous from Municipal Sewage Plant Effluents," Engineering Research Bulletin B-93, 1966, Pennsylvania State University.

4. Koenig, Louis, "The Cost of Water Treatment," Journal of American Water Works Association, pp. 290-336 (March, 1967).

5. Davies, D. S. and Kaplan, R. A., "Activated Carbon Eliminates Organics," Chemical Engineering Progress, pp. 46-50 (December, 1964).